Emotion recognition from facial and non-facial cues

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I, Zillah Boraston, confirm that the work presented in this thesis is my own.

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Abstract

The recognition of another's emotion is a vital component of social interaction, and a number of brain regions have been implicated in this process. This thesis describes a series of experiments which investigate further the neural basis of emotion recognition, and its disruption in autism, a disorder characterised by profound impairments in social and emotional understanding.

First, I attempted to determine more precisely the role of two brain regions, the amygdala and fusiform gyrus, using multivariate analysis to investigate whether the identity of observed emotions is represented in the spatial pattern of activity in these regions.

I next focused on a particular cue to emotion – that of social movement. For this purpose, I designed a novel test of emotion recognition using abstract animations. I used this in an fMRI study together with emotion recognition tasks relying on facial expression and prosody. I found that some brain regions involved in processing these more commonly studied cues were also recruited in emotion recognition from the animations.

The final studies described here are concerned with emotion recognition in autism. I administered the social movement-based test of emotion recognition to adults with autism and found a deficit in sadness recognition, which extended to the recognition of sadness from facial expressions.

Finally, I investigated the impact on emotion recognition of expertise with sensory cues, returning again to the processing of facial expressions. I employed a more subtle test of emotion processing, a posed smile discrimination task, and found impaired performance in the autism group and also reduced gaze to the eye region.

These findings are discussed in view of current models of emotion recognition, with reference to the role of the amygdala and its interactions with specialised cortical regions, and the impact of early social experience on subsequent social perceptual and social cognitive ability.

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Chapter 1 Introduction

This introduction provides an overview of our current understanding of emotion recognition. I first consider briefly the evolutionary role of emotions and their influence on attention, memory and judgement. I then turn to the recognition of emotion, and the brain areas involved. Finally I review the evidence for an emotion recognition deficit in autism, and the evidence that emotional stimuli are processed differently in individuals with this disorder.

1.1 The human emotions

1.1.1 Definition of emotion

Scientists and philosophers have struggled for centuries to agree on a clear definition of an emotion. However, the various definitions that have been proposed do share certain features. It is generally agreed that an emotion comprises both a mental and an accompanying physical or physiological state (James, 1884), that emotions are to a large degree automatic, and not under conscious control (LeDoux, 1996), and that emotions exist to help organise and motivate our behaviour, by indicating the value of events in our environment (Dolan, 2002).

In colloquial language, the word emotion is often used interchangeably with the word feeling. In fact, these words have distinct meanings. The word 'feeling' refers to the internal mental states that accompany an emotion, which are not accessible to the external observer. However, as mentioned, each emotion is also defined by the characteristic physiological changes that occur when it is experienced. The feeling of fear, for example, is frequently accompanied by changes in heart rate, and an increase in skin conductance.

1.1.2 Why we have emotions

In 1969 the term 'basic' emotions was coined to describe those emotions that are common to all human cultures, namely anger, fear, happiness, sadness, surprise and disgust (Ekman, Sorenson & Friesen, 1969). The neural mechanisms that drive these

basic emotions are likely to predate the origin of the human species itself. This is reflected in the similarity of this neural machinery across many mammalian species. The ubiquity of these basic emotions indicates that, far from being simply a by-product of an increasingly complex brain, emotions have, or at least had, a distinct survival value.

The way in which emotions confer an evolutionary advantage on the bearer is by guiding the behaviour of that individual in an adaptive way (Darwin, 1872). Each emotion promotes the type of behaviour that is adaptive in the situation that provokes that emotion. For example, fear promotes withdrawal from a dangerous situation, whereas anger motivates aggression which, for example, might be important in a territorial dispute.

As each emotion evolved to solve a particular problem in our evolutionary past, they to some extent rely on independent neural circuits (LeDoux, 1996). Far from there being a universal 'emotion centre' in the brain, the emerging picture is a more complex one with distinct, though interconnected, circuits involved in the experience of different emotions. Each of these circuits draws on a number of brain areas, including regions in both the ancient and the evolutionarily 'newer' parts of the brain.

The guiding effects of emotion on behaviour, which would have been adaptive in our ancestral environment, can still be seen today. An example of this is the way in which emotional variables can affect our performance on formal tests of attention, memory, and decision making, as detailed below.

As emotions evolved to help us respond to changes in our environment, such as the appearance of a predator, a rival or a mate, it is not surprising that they have a strong effect on the direction of attention, usually focussing attention on the object or individual that elicited the emotion. The effect of emotion on attention can be demonstrated using the Emotional Stroop test. In the Stroop test, a person is presented with a series of coloured words, and must name the colour that each word is written in. In the classic version of the test, sometimes the written word is the name of another colour. When this happens, reaction times in the task are significantly longer, due to the extra demands placed on attention by the conflicting verbal and colour

information. An even greater increase in reaction time occurs when the word in question is emotionally significant, demonstrating the extra capture of attention by the emotional content (for a review of studies using the Emotional Stroop test, see Williams, Mathews, & MacLeod, 1996).

The effect of emotion on attention can also be seen in a visual search paradigm, in which a subject must search for a target object in a field of distractors. Visual search has been shown to be more rapid for emotionally salient targets, particularly fear-related targets, such as images of snakes or spiders in a field of other images (Ohman, Flykt, & Esteves, 2001). Fear-relevant targets appear to 'pop out' of the array of distractor images, and thus be detected automatically. This occurs in all individuals, but is even more pronounced in individuals with a spider or snake phobia (Ohman et al., 2001).

Emotions also have a strong influence on memory. A commonly observed phenomenon is that we have a better memory of events if they elicit strong emotions in us. This has also been demonstrated in controlled behavioural studies (Bradley, Greenwald, Petry, & Lang, 1992; Hamann, Ely, Grafton, & Kilts, 1999). Bradley et al. (1992) found that pictures rated as highly arousing were remembered better in an immediate recall test, and in a delayed recall test one year later. This raises the possibility of a brain mechanism that enhances memory for emotionally salient stimuli, and the authors of this study speculate that the physiological component of the emotional response may be necessary for this enhancement.

The influence of emotions on our behaviour can be seen most clearly in their impact on judgements and decision making. For example, normal emotional functioning is necessary in order to make appropriate judgements of the trustworthiness of others. Individuals with impaired emotion processing due to damage to the amygdala tend to be impaired in making this kind of judgement (Adolphs, Tranel, & Damasio, 1998). Also, a person's emotional state appears to influence his or her judgement of risk. Johnson & Tversky (1983) asked participants to judge the risks of adverse events, such as disease, or accidents, that are common causes of death. They showed that a negative affect, induced by reading a report of a tragic event, led to judgements of increased risk severity, whereas a positive affect had the opposite effect. Lerner and

Keltner (2001) contrasted the effects of induced anger and fear and found that, when fearful, people were more pessimistic and, when angry, more optimistic in their estimations of risk. This was also true for naturally occurring anger and fear.

According to modern economic theory, decision making is an entirely reason-driven process that is not affected by emotion. However, given that emotions evolved as a way of indicating the value of events, it seems intuitive that they would have a constructive role to play in the decision making process. It has been argued that in fact emotions are crucial in the formation of advantageous decisions (Bechara & Damasio, 2005). Our ability to use emotional information to aid decision making appears to depend on the normal function of the ventromedial prefrontal cortex (VMPFC). This brain region is thought to be able to guide reasoning, by generating anticipatory emotional states associated with the options available in a decision. These emotional states, measurable as autonomic changes in arousal, can be used to guide reasoning. Evidence for this comes from studies in which subjects are given a gambling task, in which they have to work out which choices are likely to win them money. Subjects quickly form emotional 'hunches', which guide their choices, and these are paralleled by levels of autonomic arousal which discriminate between the different possibilities (Bechara, Damasio, Tranel, & Damasio, 1997). VMPFC lesion patients do not develop these discriminatory patterns in their arousal levels, nor the same emotional hunches (Bechara, Tranel, Damasio, & Damasio, 1996), which is likely to explain their poor performance on this task (Bechara, Damasio, Damasio, & Anderson, 1994).

1.1.3 Facial expressions of emotion

One feature most commonly associated with emotions is their characteristic facial expressions. These expressions most likely evolved as a mechanism for communicating our emotional state to others. Behaving adaptively can be greatly facilitated by being able to predict the consequences of our actions, and this is done partly by learning from the consequences of others' actions.

In 1872, Charles Darwin published his book "The expression of the emotions in man and animals" (Darwin, 1872). Despite the fact that Darwin chose not to focus on the communicative importance of expressions, a number of his observations about the

nature of expressions still influence current thinking. Darwin noted that humans share a number of facial expressions with other animals, and interpreted this as evidence against the special creation of the human race.

Another pertinent observation was that facial expressions of emotion are similar across different cultures, from which Darwin concluded that they are innate rather than learned. Darwin did not do any formal, controlled experiments to support these observations. This idea of universality was therefore not confirmed experimentally until 1969, when Paul Ekman and colleagues conducted cross-cultural studies of facial expressions (Ekman et al., 1969). Ekman travelled to a remote, pre-literate culture in Papua New Guinea and demonstrated that people here made the same facial expressions to signify certain emotions as do American citizens. Americans were able to identify correctly the emotions expressed in photographs of villagers from Papua New Guinea, and vice versa. This supports the notion that these expressions, and the experience of the emotions that underlie them, are therefore innate. Ekman described the emotions that fall into this category as 'basic' emotions. The six emotions most widely acknowledged as 'basic' are happiness, sadness, anger, fear, surprise and disgust.

In addition to being innate, there is evidence that the facial expressions that underlie these basic emotions are generated automatically, rather than being under conscious control. For example we appear to mimic, automatically and unconsciously, the facial expressions of others. Pictures of happy faces evoke contraction of the *Zygomaticus major* muscle, which raises the lips to produce a smile, whereas pictures of angry faces evoke contraction of the *Corrugator supercilii* muscle, which lowers the brow to produce a frown (Dimberg, 1982; Dimberg & Thunberg, 1998). This occurs even when the faces presented are masked (Dimberg, Thunberg, & Elmehed, 2000) and also occurs in response to dynamic stimuli (Sato & Yoshikawa, 2007).

1.2 The recognition of emotion

Our ability to communicate using facial expressions requires us to be able both to make these expressions and to recognise them. In addition, many other cues have been shown to be important in the recognition of emotion, including tone of voice (Pell,

2002) and movement patterns (Heberlein, Adolphs, Tranel, & Damasio, 2004; de Gelder, 2006).

Here, I summarise the current understanding of the mechanisms of emotion recognition in the normal brain, before looking at implications of this for the developmental disorder of autism, in which there is some evidence of disrupted emotion recognition. This review will focus on Ekman's six 'basic' emotions, as these have been the subject of much research. The main focus will be on emotion recognition from facial expression as, again, this has been the cue most extensively researched. I will largely draw on evidence from human studies, though animal evidence that is particularly relevant is included.

It is important that a clear distinction is drawn between emotion recognition and emotional experience, as these are sometimes confused. Studies of emotional experience typically use emotion induction, for example eliciting a sad mood by playing sad music to the participant. Studies of emotion recognition tend to use images of facial expression. There is no reason to suppose that the brain mechanisms of emotion recognition are the same as those involved in emotion experience. Although there may be some overlap, these involve distinct underlying cognitive processes.

Information about how the brain is able to recognise emotion comes from two main sources: data from patients with selective brain lesions, and functional imaging data from positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) studies.

It has been consistently demonstrated that damage to certain brain areas can impair the recognition of emotion. However, it is sometimes difficult to infer the precise role of the lesioned area. It could be involved directly in emotion recognition, or alternatively it could have a perceptual role, 'upstream' from the brain areas involved in emotion recognition. These alternatives can be distinguished by including an appropriate control task in the testing battery, i.e. a task with similar perceptual and attentional demands. Another important issue in task design is ensuring that task difficulty is matched across all of the emotions being tested, to avoid the discovery of

'selective deficits' that are an artefact of poorly matched tasks.

More information about the precise role of a brain area can be obtained from functional imaging. Some functional imaging studies have simply exposed subjects to emotionally informative stimuli, such as facial expressions, and measured the resulting brain activity when contrasted with neutral stimuli. Others have included an explicit emotion recognition task, contrasted with a control task. These two approaches will not necessarily result in activation of the same brain areas.

This section of the introduction will look at the brain areas involved in emotion recognition (Figure 1), and the evidence for the involvement of each of these areas, from lesion and neuroimaging data. I will look in more depth at the role of one particular area – the amygdala. I will review the evidence for separate neural systems for the identification of different emotions. Finally, I will briefly consider the developmental trajectory of emotion recognition ability.

1.2.1 Brain areas involved in emotion recognition

1.2.1.1 Amygdala

The amygdala is a small structure found bilaterally in the medial temporal lobe, close to the temporal poles. It is probably the brain structure most studied in relation to emotion recognition.

The first evidence for the involvement of the amygdala in emotion recognition came from the observation that damage to the amygdala impaired the recognition of emotion, first demonstrated by Adolphs et al. (1994) in their study of SM, a patient with bilateral amygdala damage. SM was impaired in recognising facial expressions of fear. This finding has since been replicated by other groups, working with other amygdala lesion patients (Broks et al., 1998; Anderson & Phelps, 2000a; Anderson, Spencer, Fulbright, & Phelps, 2000b; Schmolck & Squire, 2001). Anderson and Phelps (2000a) found that the emotion recognition deficit was not limited to fear, but encompassed sadness, happiness and disgust.

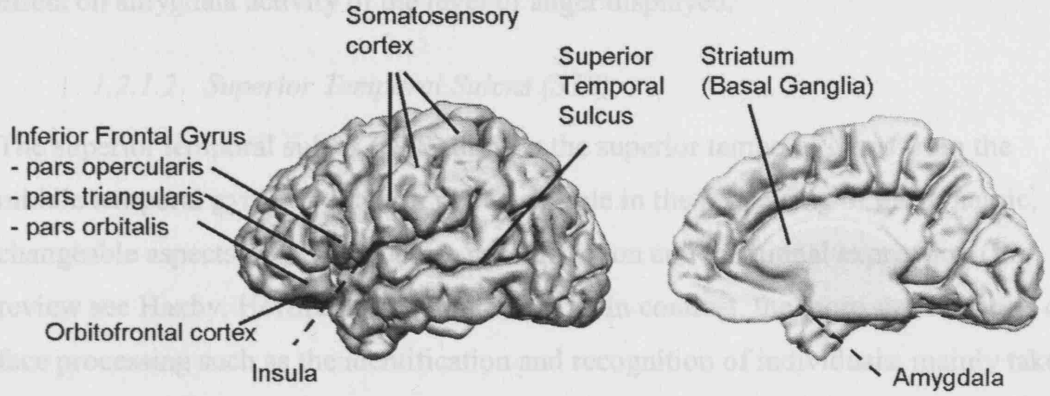

Figure 1. Brain regions implicated in the recognition of emotion. N.B. the amygdala and insula are not visible from a surface view or a medial view of the brain.

Functional imaging studies have consistently shown that the amygdala is activated by facial expressions of emotion (Breiter et al., 1996; Morris et al., 1996; Phillips et al., 1998; Phillips et al., 1997; Fitzgerald, Angstadt, Jelsone, Nathan, & Phan, 2006; Britton, Taylor, Sudheimer, & Liberzon, 2006), and a number of studies have suggested that this activity is selective for particular emotions. Concordant with the findings of amygdala lesion studies, several studies have found amygdala activation in response to facial expressions of fear (Breiter et al., 1996; Morris et al., 1996; Phillips et al., 1997; Phillips et al., 1998), even when the images are rendered invisible by backward masking (Whalen et al., 1998). There is also evidence that the eye region of a fearful face is sufficient to activate the amygdala (Whalen et al., 2004). These studies vary in the contrasts used. Whalen et al. compared fearful to happy faces, whereas Breiter et al. and Phillips et al. used a fearful versus neutral contrast. Morris et al. (1996) used 'morphed' faces, generated through digital manipulation, which varied along a continuum from fearful through neutral to happy.

Some studies have found an amygdala response to emotions other than fear. Breiter et al.'s (1996) results also showed an amygdala response to happy faces when compared to neutral faces. Killgore & Yurgelun-Todd (2004) found a response to happy versus sad faces, even though the faces were rendered invisible by backward masking. A response to sad faces has also been found. Blair et al's PET study (Blair, Morris, Frith, Perrett, & Dolan, 1999) looked at the effect of sad and angry faces on amygdala activation, using morphed faces. They found a positive relationship between the sadness of the face and the level of amygdala activation. In contrast, they found no

effect on amygdala activity of the level of anger displayed.

1.2.1.2 Superior Temporal Sulcus (STS)

The superior temporal sulcus (STS) divides the superior temporal gyrus from the middle temporal gyrus. It plays an important role in the processing of the dynamic, changeable aspects of a face, such as gaze direction and emotional expression (for review see Haxby, Hoffman, & Gobbini, 2002). In contrast, the more static aspects of face processing such as the identification and recognition of individuals, mainly take place in the fusiform cortex. Narumoto et al. (2001) used fMRI to study healthy adults performing discrimination tasks using images of facial expression. They found that the STS was more active when subjects paid attention to the emotional expression of a face, rather than the identity. The same has been found using MEG (Streit et al., 1999). The involvement of the STS in processing facial expression is part of a broader role in the sensory processing of socially relevant stimuli (Allison, Puce & McCarthy, 2000), which also include biological motion (Howard et al., 1996; Bonda, Petrides, Ostry & Evans, 1996) and eye gaze direction (Wicker, Michel, Henaff & Decety, 1998; Hoffman & Haxby, 2000). Activity in this region is influenced by the perceived meaning of a stimulus (Decety et al., 1997), and the social context in which it appears (Pelphrey, Singerman, Allison & McCarthy, 2003), suggesting that its activation is subject to top-down influences.

1.2.1.3 Orbitofrontal cortex (OFC)

Several studies have shown that damage to the OFC impairs emotion recognition from facial expressions (Hornak, Rolls, & Wade, 1996; Hornak et al., 2003; Blair & Cipolotti, 2000). Hornak et al. (2003) compared the effects of lesions to different parts of the prefrontal cortex in 35 patients, and found lesions to one or both sides of the OFC impaired emotion recognition, though impairment did not occur in all cases. It has been reported that, compared to amygdala damage, damage to the OFC causes more pronounced changes in emotional and social behaviour (Rolls, 2007).

Single neuron recordings from humans being treated for epilepsy show that cells in the OFC can discriminate between fearful and happy faces with a response latency of only 120-160ms (Kawasaki et al., 2001). Based on these findings, it has been suggested that the OFC, along with the amygdala, is involved in the coarse early

categorisation of emotional expressions, prior to more detailed processing in other brain areas (Adolphs, 2002).

1.2.1.4 Inferior frontal cortex

Imaging studies have found activation of the various parts of the inferior frontal gyri during emotion recognition tasks (George et al., 1993; Nakamura et al., 1999; Gorno-Tempini et al., 2001). These areas show a strong effect of task, being activated by explicit emotion recognition tasks, but not by control tasks using the same stimuli, such as judging the gender of the face, or the colour of the background. This has been found both using PET (George et al., 1993; Nakamura et al., 1999) and fMRI (Gorno-Tempini et al., 2001). In two of these studies (Nakamura et al., 1999; Gorno-Tempini et al., 2001) the activity was limited to the right side of the brain. This effect of tasks suggests involvement of the IFG in top-down aspects of emotion processing.

1.2.1.5 Somatosensory cortex

The somatosensory cortex (SI and SII) carries representations of our own bodily states, but there is evidence that it is also involved in emotion recognition. Adolphs et al. (2000) found, in a study of 108 patients with brain damage, that damage to the right somatosensory cortex impaired the recognition of facial expressions of emotion.

One theory is that the role of the somatosensory cortex in emotion recognition is one of simulation. Adolphs (Adolphs, 1999) proposes that when we observe the facial expression of another person, a somatosensory representation is elicited that simulates the internal state of that person, thus allowing us to identify the emotion that brought about that facial expression. In doing this we draw on information from our own previous emotional experiences. The involvement of the somatosensory cortex in the simulation of others' emotional states is discussed further in section 1.2.4 of this introduction.

The insula is part of the visceral somatosensory cortex, involved in the processing of smells and visceral sensations. fMRI studies have shown that the insula is activated when a person experiences disgust (Wicker et al., 2003). There is also evidence of its involvement in the recognition of facial expressions of disgust. Damage to the insula impairs the recognition of disgust (Calder, Keane, Manes, Antoun, & Young, 2000), and fMRI studies have shown that the insula responds to facial disgust (Phillips et al.,

1998; Phillips et al., 1997; Sprengelmeyer, Rausch, Eysel, & Przuntek, 1998; Wicker et al., 2003), though these studies did not include an explicit emotion recognition task. Wicker et al. showed an overlap between the brain areas involved in experiencing disgust, and viewing facial expressions of disgust. They propose a visceromotor role for the insula, in transforming sensory input into visceral feelings of disgust.

1.2.1.6 Basal ganglia

Early evidence for the involvement of the basal ganglia in emotion recognition came from the study of patients with Huntington's disease, a genetic condition which in the initial stages leads to damage to the basal ganglia, in particular the striatum. Sufferers of Huntington's are impaired in recognition of facial expressions of several emotions, but show the greatest impairment in perception of disgust (Sprengelmeyer et al., 1996; Wang et al., 2003; Montagne et al., 2006, but see Milders et al., 2003). This deficit also occurs in patients who carry the gene for Huntington's, even before their symptoms appear (Gray, Young, Barker, Curtis, & Gibson, 1997). The basal ganglia are highly connected to insula, which has also been implicated in Huntington's disease, and also appears to be involved in the recognition of disgust.

Further evidence for the involvement of the basal ganglia in emotion recognition comes from studies of patients with Parkinson's disease, another disorder associated with dysfunction of the basal ganglia. Individuals with Parkinson's disease show evidence of impaired emotion recognition (Blonder, Gur & Gur, 1989; Jacobs, Shuren, Bowers & Heilman, 1995; Sprengelmeyer et al., 2003). Some studies, however, have failed to find such a deficit, leading to claims that previously reported deficits might not be robust or consistent (Adolphs, Schul & Tranel, 1998). Another possibility is that the emotion recognition deficits in Parkinson's disease are restricted to problems with vocal, and not facial, stimuli (Pell & Leonard, 2005; Dara, Monetta & Pell, 2008, but see Kan, Kawamura, Haseqawa, Mochizuki & Nakamura, 2002). As with studies of Huntington's patients, there is some evidence that deficits might be particularly severe for the recognition of disgust (Sprengelmeyer et al., 2003; Pell & Leonard, 2005; Suzuki, Hoshino, Shigemasu & Kawamura, 2006), but problems with recognition or judgement tasks based on other emotions, such as anger and fear, have also been reported (Dara, Monetta & Pell, 2008).

1.2.2 The amygdala in emotion recognition

The amygdala is probably the part of the brain that has been most extensively studied in emotion recognition research. In this section I will review this research in more detail, and address the question of what role the amygdala plays in emotion recognition.

1.2.2.1 Does the amygdala discriminate between emotions?

Early imaging studies, described in section 1.2.1.1 of this introduction, found the amygdala response to be selective to particular emotions. However, different studies have found amygdala responses to different emotions and, overall, there is no clear picture of which emotions the amygdala response is selective for. More recent studies indicate that the amygdala responds to most, if not all, emotions. Fitzgerald et al. (2006) found amygdala activation in response to facial expressions of five emotions (angry, happy, sad, fearful and disgusted), as well as neutral faces when compared to baseline stimuli, and statistical comparisons revealed that the amygdala did not discriminate between these emotions in its level of activity. Britton et al. (2006) also found amygdala activation in response to angry, happy, sad, fearful and neutral faces.

There are several possible explanations for these findings. One is that the amygdala does not process information about the identity of individual emotions, and merely serves as a detector of emotionally salient visual stimuli. Another is that the identity of emotions is reflected in the pattern of neural activity, but that this is at too small a spatial scale to be picked up by conventional fMRI analysis. To differentiate between these two possibilities, it is necessary to look at the amygdala at a smaller spatial scale. The amygdala is a collection of several distinct nuclei, and this structural heterogeneity is likely to be reflected in a considerable degree of functional heterogeneity (Swanson & Petrovich, 1998), yet current imaging studies do not usually pay attention to where precisely in the amygdala the activity is found.

Two recent developments in functional imaging will enhance the spatial resolution available in studies of the amygdala. The first is an increase in the field strength at which the amygdala can be imaged. The second is the way in which fMRI data are analysed. fMRI data are typically analysed in a univariate manner, i.e. the activation profile of each voxel is analysed individually, so patterns in activity across voxels are

lost. The technique of multivariate pattern recognition uses the information in the raw BOLD signal to train a pattern classifier to discriminate between the BOLD patterns produced by different stimuli (Kamitani & Tong, 2005), and might potentially have applications in the analysis of amygdala activation patterns in response to different emotions. This is described in more detail in Chapter 3 of this thesis.

1.2.2.2 Effect of task on amygdala activity

Functional imaging data support the evidence from brain lesions that the amygdala is involved in the processing of emotional facial expressions (Breiter et al., 1996; Morris et al., 1996; Phillips et al., 1998; Phillips et al., 1997; Fitzgerald, Angstadt, Jelsone, Nathan, & Phan, 2006; Britton et al., 2006). However, none of these studies included an explicit emotion recognition task. In order to show that the amygdala is specifically recruited for emotion recognition, it is helpful to include a task that requires emotion recognition, together with a control task.

A few studies have included explicit tasks of emotion recognition (Vuilleumier, Armony, Driver, & Dolan, 2001; Gorno-Tempini et al., 2001; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Winston, O'Doherty, & Dolan, 2003; Williams, McGlone, Abbott, & Mattingley, 2005). These studies all included comparison tasks using the same stimuli, such as judging the gender of the faces (Gorno-Tempini et al., 2001; Winston et al., 2003), matching images of houses that were also present in the visual field (Vuilleumier et al., 2001; Williams et al., 2005), or judging the orientation of bars in the periphery of the visual field (Pessoa et al., 2002).

In congruence with other functional studies, most of these studies found a main effect of emotion on amygdala activity (Gorno-Tempini et al.: disgusted faces > happy faces, Vuilleumier et al. and Pessoa et al.: fearful faces > neutral faces, Winston et al.: high intensity emotion > low intensity emotion). Some studies found an interaction between the emotion present and the task (Gorno-Tempini et al., 2001; Pessoa et al., 2002; Williams et al., 2005), whilst others did not (Vuilleumier et al., 2001; Winston et al., 2003). Only one of these studies (Pessoa et al., 2002) found a main effect of task on amygdala activation. An interaction between emotion and task would indicate that the amygdala is more strongly activated by emotional stimuli when the observer

is paying attention to the emotional aspect of these stimuli. In other words, it would show that the amygdala is influenced by top-down processing, rather than activity in this region being driven by the stimuli alone.

1.2.2.3 Role of the amygdala

The lack in some studies of an interaction between emotion and task in the amygdala could indicate that its role is largely a perceptual one, prior to emotion recognition which may depend on other neural structures. This is the role proposed by Winston et al. (2003), based on the results of their imaging study discussed above.

It has been proposed that the amygdala is especially involved in the fast detection of emotionally relevant stimuli (LeDoux, 1996; LeDoux, 2000). According to this view, the amygdala response to facial expressions of emotion, in particular fear, is due to their emotional salience. Facial expressions of fear are thought to be particularly salient as they can signal a potential threat (Adolphs et al., 1999). Adams and colleagues (Adams, Gordon, Baird, Ambady & Kleck, 2003) have proposed an explanation for why the amygdala responds more strongly to fear than to anger. Most studies of emotion recognition have used photographs of faces staring directly ahead. This group claims that a fearful face with direct gaze is a highly ambiguous stimulus, as the cause of their fear, and hence the threat to the observer, is unclear. In contrast, an angry face staring straight ahead is an unambiguous indication of threat – the threat is the person making the face. The researchers propose that the amygdala is sensitive to the ambiguity of threatening stimuli. They show that when angry faces are made ambiguous by averting the gaze, they also elicit high levels of amygdala activation.

There is some evidence of a role for the amygdala in enhancing the cortical processing of such emotionally salient stimuli. Vuilleumier et al. (2004) studied the neural response to fearful faces in subjects with and without lesions to the amygdala. They found that the fusiform cortex responded more to fearful than to neutral faces in controls, but not in subjects with lesions to the amygdala. They concluded that the amygdala enhances the fusiform response to the fearful faces, and propose that this enhancement is not to aid emotion recognition, but rather to boost memory of emotionally salient or threatening stimuli.

Goldman and Sripada (2005) argue that the importance of the amygdala in the recognition of emotions, particularly fear, is due to its role in emotional experience. They point out that amygdala lesion patients are not only impaired in fear recognition, but do not experience fear as others do (Bechara et al., 1995; Sprengelmeyer et al., 1999).

Adolphs et al. (2005) propose the importance of the amygdala in emotion recognition is due to its influence in directing attention to the salient regions of the face. They investigated in more detail the abilities of SM, the amygdala lesion patient described in their earlier study (Adolphs et al., 1994). They used a novel technique called the 'bubbles' task (Gosselin & Schyns, 2001) to see which parts of the face SM was using to make her judgement of emotion. This task involves a large number of trials, in each of which only a small part of the face is visible, and information is only available within a specific band of spatial frequencies. The subject's discrimination accuracy on each trial is recorded. It is then possible to perform a regression using the location of these visible regions, or 'bubbles', to see which regions of the face are actually useful in terms of improving the subject's performance. Adolphs et al. found that SM did not make use of available information from the eye region. A subsequent eye-tracking experiment confirmed that SM did not look at the eyes when viewing these facial expressions. They propose that this is why her recognition of emotions is impaired, and that as the recognition of fear depends more heavily on the eye region of the face, this explains her particular deficit in fear recognition. It also explains why her recognition of fear from auditory cues is unimpaired. When SM was specifically instructed to look at the eyes, her fear recognition ability was restored, showing that she retained the neural capacity for fear recognition. A challenge to this explanation for SM's deficit is presented by the finding that lesions to the amygdala also impair the recognition of fear from voices (Scott et al., 1997), suggesting that the amygdala's role in fear recognition might be more complex than simply directing attention to the appropriate region of the face.

It has been suggested that the amygdala is also important in the initial learning process involved in emotion recognition, which allows emotion recognition circuits in the temporal and parietal cortices to develop properly (Adolphs, Damasio, Tranel, & Damasio, 1996). The amygdala is thought to link perceptual information from

emotional expressions with conceptual knowledge of those emotions, stored in cortical regions. The timing at which a lesion to the amygdala occurs will therefore affect the impact of the lesion. Lesions early in life, as seen in patient SM (Adolphs, Tranel, Damasio, & Damasio, 1995; Adolphs, Tranel, Damasio, & Damasio, 1994), have a more detrimental effect on emotion recognition than those later in life (Hamann et al., 1996).

1.2.2.4 Laterality in the amygdala

A number of models of emotional processing incorporate the idea that this function is to some degree lateralised within the brain. In some models the right hemisphere is held to be dominant for all emotional processing; in others, emotions are lateralised according to valence, with positive and negative emotions preferentially processed by the left and right hemispheres respectively (for a review see Zald, 2003). These models are largely based on data from the prefrontal cortex (Davidson & Irwin, 1999; Davidson, 2002), and can not necessarily be extrapolated to the amygdala, either for emotion processing in general, or for the processing of emotional facial expressions.

Results from lesion studies can help to establish which of the amygdalae, if either, is necessary for emotion recognition. There is some evidence that emotion recognition deficits only occur with bilateral, not unilateral, amygdala damage (Adolphs et al., 1995). However, Anderson et al's (2000b) study found that right amygdala damage was sufficient to impair emotion recognition. Additionally, Adolphs et al. (1999) found a large amount of heterogeneity in the abilities of amygdala lesion patients, with some patients with bilateral amygdala damage being unimpaired in fear recognition.

Functional imaging data are less informative on the question of the necessary neural substrate for emotion recognition, but can provide insight into putative functions of the two amygdalae in the processing of facial expressions of emotion. One idea that has emerged is that the left amygdala dominates for the conscious processing of such stimuli, and the right for unconscious (Morris, Ohman, & Dolan, 1998). An alternative view is that the left amygdala is responsible for the detailed cognitive appraisal of emotional faces, whilst the right amygdala is activated more quickly and automatically, and is involved in producing an autonomic response to such faces, and

to other emotionally salient stimuli (Glascher & Adolphs, 2003). A complication in the interpretation of fMRI findings is the differential rates of habituation of the left and right amygdalae, with faster habituation in the right amygdala (Wright et al., 2001). This could partly explain why activation of the left amygdala is more commonly found in fMRI studies (Wager, Phan, Liberzon, & Taylor, 2003), but is not thought to be the only factor responsible for this discrepancy (Baas, Aleman, & Kahn, 2004).

1.2.3 Are there separate neural systems for recognising basic emotions?

At present, there is insufficient evidence to suggest that the recognition of each of the basic emotions is driven by a separable neural substrate. This could be in part due to the low statistical power of individual imaging studies. The two emotions for which there is the most evidence for separate recognition systems are disgust and fear (for a review of this area, see Calder, Lawrence, & Young, 2001).

There is strong evidence implicating the basal ganglia and the insula in the recognition of disgust, from brain lesion data, clinical groups, and functional imaging studies. However, the dissociation of disgust from other emotions is not absolute – Huntington's patients exhibit problems in the recognition of other emotions, such as anger and fear (Sprengelmeyer et al., 1996) and a recent study of 475 individuals with Huntington's disease found that deficits extended to any negative facial emotion (Johnson et al., 2007). There is also a need for more functional imaging studies with specific emotion recognition tasks, to demonstrate that these brain areas are not simply activated by expressions of disgust, but are involved in their recognition.

In the case of fear recognition, the data in support of an isolable neural subsystem are plentiful, but by no means unequivocal. Initially, the amygdala was thought to play a special role in the identification of facial expressions of fear; lesions to the amygdala were found to impair fear recognition selectively (Adolphs et al., 1994), and imaging studies suggested that the amygdala was selectively activated by fearful faces. However, subsequent lesion studies found impairment in recognition of other emotions (Adolphs et al., 1999; Anderson et al., 2000a; Schmolck et al., 2001). Also, as described earlier, a subsequent study of SM, the original lesion patient studied by

Adolphs et al. (1994), suggests that the selectivity of her deficit is due to the importance of the eye region in recognising fear, and the unusual inability of SM to use information from the eye region of the face (Adolphs et al., 2005).

It has also been suggested that selective deficits in fear recognition were found simply because fear is more difficult to recognise, even for normal subjects. Rapcsak et al. (2000) found that when task difficulty was taken into account, many lesion patients could no longer be considered to have fear-specific deficits in emotion recognition. It has been proposed that this difficulty effect depends on the precise task (Adolphs, 2002). If the task involves selecting the appropriate emotion label from a choice of the six basic emotions, fear is easily confused with surprise. It is possible that if 'surprise' was not one of the options available in a forced choice task, the recognition of fear would be no more difficult, for control subjects, than that of other emotions. In this case, an apparent fear-specific deficit in a lesion patient would be more likely to be genuine.

Evidence from brain imaging follows a similar pattern. Although the early studies suggested that the amygdala response was selective for fearful faces, subsequent imaging studies indicate that these findings extend somewhat to other emotions (Breiter et al., 1996; Killgore & Yurgelun-Todd, 2004; Blair et al., 1999). In addition, an alternative explanation for the particularly strong response to fearful faces, as described earlier, is that it is an artefact of the direction of gaze in the fearful face (Adams et al., 2003).

1.2.4 Recognition of emotions by simulation

An extension to the concept of separate neural systems for the recognition of certain emotions is the idea that for some emotions (fear, disgust and anger), the brain regions involved in recognising the emotion are the same regions as are involved in the experience of the emotion itself. Amygdala lesion patients show abnormalities in the experience and recognition of fear (Bechara et al., 1995; Sprengelmeyer et al., 1999), the amygdala is activated during fear conditioning (Buchel, Morris, Dolan, & Friston, 1998), and by viewing facial expressions of fear (Breiter et al., 1996; Morris et al., 1996). Similarly, lesions to the basal ganglia and the insula lead to problems with the

experience and recognition of disgust (Calder et al., 2000), and the same parts of the insula are activated by both the experience and the observation of disgust (Wicker et al., 2003). Finally, the experience of anger has been linked to activation of the dopamine system in the brain. Administering sulphride, an antagonist to D_2 dopamine receptors, both reduces the anger response, and impairs recognition of facial expressions of anger (Lawrence, Calder, McGowan, & Grasby, 2002).

Goldman and Sripada (2005) see these parallels as evidence that the recognition of facial expressions of emotion occurs through a process of simulation. In other words, a person viewing a facial expression will interpret it by attempting to recreate the experience of that emotion. Simulation could occur by making use of a combination of forward and inverse models. In motor learning theory, a forward model is one which predicts the sensory consequences of a planned action. An inverse model, in contrast, retrieves the motor plan which would be needed to achieve a desired sensory state. Recognition of emotions by simulation could therefore progress by using an inverse model to retrieve the motor plan for the facial expressions seen in other individuals, and then applying a forward model to predict the emotional states associated with these motor plans.

Several lines of evidence point towards a simulation mechanism for the understanding of emotions. Premotor areas are activated when viewing facial expressions of emotion (Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003), which could indicate the retrieval of motor plans using an inverse model. The application of these plans to a forward model could explain the activation of facial musculature, and the somatosensory cortex, when viewing facial expressions of emotion, and the activation of brain systems involved in emotion experience – the amygdala, insula and dopamine systems. (For a review of different possible models of simulation, see Goldman & Sripada, 2005.) Wicker et al. (2003) propose that a simulation-based emotion recognition system such as this could have evolved from a more primitive mechanism for emotion contagion, which would also have been evolutionary useful. For example, the contagion of disgust could have helped individuals to avoid diseased food. Most evidence for emotion recognition from simulation comes from studies using facial expressions of emotion. However, this could also apply to emotions conveyed through other cues, such as prosody and body movements. This would require a separate set of

forward and inverse models to incorporate the necessary motor plans.

Of relevance to the idea of emotion recognition by simulation is the idea that humans possess a mirror-neurone system, with a putative role in emotion contagion, imitation, and emotion recognition. Mirror neurones were first discovered in the rostral part of the ventral premotor cortex of macaques (area F5). They are so-called because they are active both when a monkey performs an action and when it observes the same action performed by another monkey (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996).

There is some evidence for a comparable mirror neuron system (MNS) in humans. The results of EEG (Cochin, Barthelemy, Roux, & Martineau, 1999) and MEG (Hari et al., 1998) studies show that the motor cortex is activated when people observe an action performed by another person. Additional evidence for comes from Fadiga et al's (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995) study using transcranial magnetic stimulation (TMS). Here, people observed an action whilst electromyogram (EMG) recordings were taken from the muscles that would perform that action. At the same time, the motor cortex was stimulated using TMS. Observing an action lowered the threshold to TMS, measurable as an increase in EMG activity in the muscles. This is evidence that observation of the action is activating the premotor system in humans as it does in monkeys.

The MNS in humans is thought to involve neurons in the posterior parietal lobe, and in the pars opercularis (Brodmans area 44), in the posterior part of the IFG (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). fMRI studies show that observing the actions of others leads to activity in these regions (Johnson-Frey et al., 2003), and imitating these actions leads to a further enhancement of this activity (Carr et al., 2003). It has been proposed that the MNS is involved in the recognition of others' emotional states (Carr et al., 2003; Leslie, Johnson-Frey & Grafton, 2004). In congruence with the idea of forward and inverse models, this 'motor theory of empathy' postulates that the same premotor neurones involved in generating a particular emotional facial expression in oneself are involved in the recognition of that expression in others (Leslie et al., 2004).

One challenge which simulation models of emotion recognition will have to address is

the fact that in some cases a particular emotion expressed by another individual might elicit the experience of a very different emotion in the observer. For example, seeing an angry person might induce fear in the observer. Thus in addition to the activation of 'angry' motor representations in the observer as proposed by a simulation model, fearful motor representations would also be activated. A simulation model would need to explain how the activation of two motor patterns could be disambiguated to differentiate correctly between the felt and observed emotions. One possibility is that the activation of these two representations would have different timecourses and could thus be distinguished from one another.

1.2.5 The development of emotion recognition

The study of the development of emotion recognition ability throughout infancy and childhood is a potential avenue for exploring the brain mechanisms that might underlie this ability. However research into this ability in infants comes with its own particular challenges. One such difficulty is in assessing accurately the extent to which an infant can understand the meaning of facial expressions of emotion. For example, even at the age of 7 months, infants show some ability to categorise emotions. Caron et al. (1982) tested the ability of a group of 36 30-week-old infants to categorise facial expressions of happiness and surprise, using a habituation paradigm. They found that infants were able to differentiate between these expressions at 30 weeks, but not before. However, due to the lack of verbal ability at this age, it is not possible to determine whether these infants understood the meaning behind the emotions.

Although emotion recognition skills appear to start developing at an early age, they continue to improve throughout early childhood. MacDonald et al. (1996) tested the emotion recognition abilities of 138 children aged between 3 and 6, and found a steady improvement in performance with age. A number of other studies have found this orderly improvement throughout childhood, variously looking at age ranges of 4-10 years (Bruce et al., 2000), 4-15 years (Herba, Landau, Russell, Ecker, & Phillips, 2006), and 5-11 years (Durand, Gallay, Seigneuric, Robichon, & Baudouin, 2007). Where studies have looked at the developmental trajectories of individual emotions, there have been some differences reported. Herba et al. found that the recognition of some emotions was more strongly influenced by increasing age – fear was most

strongly influenced, followed by disgust, happiness, and sadness, whilst age showed no influence on anger recognition ability. Durand et al. found that the recognition of different emotions developed at different rates, with fear and disgust recognition developing more slowly for happiness and sadness recognition.

There is also evidence that the actual neural processing of facial emotions undergoes a protracted period of maturation. Batty and Taylor (2006) analysed ERP data from 82 children, aged between 4 and 15 years. They found that even the oldest children in the study had not fully developed the classic ERP responses that adults typically exhibit in response to facial expressions of emotion.

Also relevant to these findings concerning the development of emotion recognition are current ideas pertaining to the development of face processing in general, which has been a subject of many decades of research and debate. One ongoing topic of discussion is the extent to which postnatal experience plays a role in the development of face processing ability. According to one viewpoint, this ability arises from prespecified modules which are specialised for processing socially relevant visual input such as information from faces, and postnatal experience has little impact on this. The alternative perspective holds that it is infants' extensive exposure to social stimuli early in life that drives the development of face processing ability. Increasingly popular, however, is a viewpoint in between these two extemes, which posits that innate biases to attend to certain stimuli, together with exposure to these stimuli, shape the development of face processing abilities (see Johnson, 2001).

A related topic of research is into the neurobiological changes behind these advances in behavioural ability seen during development. Much research into this issue has focussed on the cortical mechanisms underlying the development of face-processing abilities, but some generalisations are possible to other social cognitive abilities such as emotion recognition. Johnson (2001) describes three alternative mechanisms by which neural development might lead to changes in behavioural ability. According to the *maturational* perspective, the emergence of a new cognitive function is likely to follow the maturation of a specific brain region which has previously been largely inactive. In contrast, the *interactive specialisation* viewpoint holds that multiple relatively unspecialised pathways may initally act in parallel to subserve a particular

cognitive function, but that differing initial biases of these pathways, combined with interaction between them (including an element of competition) will lead to subsequent specialisation of pathways for particular types of input or task. Critical to this viewpoint is the idea that the same behaviour can be mediated by different structures and pathways. Finally, the *skill-learning hypothesis* is based on the idea that the neural substrate mediating a particular behaviour may depend on the stage of acquisition of this behaviour, with certain brain regions being active during the acquisition of new skills, and other regions being involved only when a certain level of expertise has been acquired.

1.3 Emotion recognition in autism

1.3.1 The autism spectrum

Autism is a pervasive developmental disorder, characterised by a triad of impairments: social communication problems, difficulties with reciprocal social interactions, and unusual patterns of repetitive behaviour (Wing & Gould, 1979). It was first described in 1943 by Leo Kanner, a child psychiatrist (Kanner, 1943). The prevalence of autism is estimated at 1 to 2 per thousand individuals (Fombonne, 1999).

There is increasing evidence that autism is not a categorical disorder, but instead lies on a continuum, along with Asperger Syndrome and Pervasive Developmental Disorder Not Otherwise Specifies (PDD-NOS). These conditions are collectively referred to as the Autism Spectrum Disorders (ASDs). A recent study estimated the prevalence of all childhood ASDs at just over 1% (Baird et al., 2006). Classical autism of the type first described by Kanner is typically associated with mental retardation. However, approximately 20% of people with autism have a normal or above-normal IQ. Individuals with Asperger syndrome do not suffer from language delay or mental retardation, but still have the impairments characteristic of autism in reciprocal social interaction, abnormal patterns of repetitive behaviour, and social communication difficulties.

Within the autism spectrum, there is marked heterogeneity in symptomatology within

each of the three domains of impairment. Social communication difficulties can range from subtle pragmatic language difficulties to a complete absence of spoken language. Repetitive behaviours range from simple motor stereotypies such as rocking, or an obsessive desire for sameness, to unusually restricted interests. Similarly, reciprocal social interaction difficulties can range from a complete lack of interaction with peers to more subtle deficits such as an inability to use appropriate eye contact.

Despite the vast amount of past and continuing research focussed on ASDs (see Volkmar, Lord, Bailey, Schultz, & Klin, 2004), factors affecting the development of these disorders are still largely unknown. There is evidence for a strong genetic component, with concordance among monozygotic twins being 4 times higher than in dizygotic twin pairs. This genetic component is likely to be the result of several genes interacting with one another (Pickles et al., 1995).

In their 1977 investigation into heritability of autism, Folstein & Rutter found that when they broadened their criteria to include milder impairments that did not reach clinical cutoff for autism, heritability increased markedly (Folstein & Rutter, 1977). This led to the concept of the 'broad autism phenotype' (BAP). The idea behind this is that what is inherited in families is not severe autism, but a milder predisposition towards autistic traits, which when combined with environmental influences might develop into an ASD in some cases.

Because of the strong heritability of the BAP, the concept is likely to be useful in the search for genes that are linked to the development of autism. This is undoubtedly one reason behind the recent increase in studies investigating the inheritance of autistic traits within families, and in twin pairs. These studies have revealed that traits typical of autism, such as repetitive behaviour patterns, and social communication deficits, tend to aggregate together in families. Piven et al. (1997b) tested the parents from 25 families with more than 1 child with autism. They found a high incidence of personality traits characteristic of autism (eg aloofness, rigidity, anxiety, hypersensitivity to criticism) and many parents with few close friendships, communication deficits (including a history of language delay) and problems with executive function, amongst other deficits.

With the advent of increasingly sophisticated neuroimaging techniques, a parallel line of research has focussed on the underlying neurobiological basis of autism spectrum disorder. A large number of studies have found both structural and functional abnormalities in the autistic brain. However as yet, no core neural mechanism has been uncovered that is capable of explaining both the range of symptoms that are associated with autism and the concomitant sparing of certain abilities, such as preserved intelligence in many cases. Such a mechanism would also need to be able to explain the heterogeneity in symptoms found across the autism spectrum (Bachevalier & Loveland, 2006). In the next section of this introduction I will give an overview of the evidence for structural abnormalities in the autistic brain. A review of functional MRI studies of autism occurs later in this introduction, and is restricted to studies linked to emotion processing.

1.3.2 Structural abnormalities in the autistic brain

Numerous studies have sought to investigate whether there are consistent structural differences in the autistic brain. In many cases, the results have been somewhat equivocal, which is perhaps due to the small power of individual studies (Stanfield et al., 2007).

Firstly, there have been reports of a greater total brain volume in autism (E.g. Sparks et al., 2002), although other studies have failed to find this (e.g. Kates et al., 2004). There is some evidence that this may depend on age, being present only in younger subjects (Aylward et al., 2002), though this is not entirely consistent (e.g. see Piven et al., 1995).

Other studies have reported on the size of specific brain regions, such as the hippocampus. Here, again, the results are equivocal, with some studies reporting larger hippocampi in autism (Sparks et al., 2002), others smaller (Aylward et al., 1999), and others no difference (Haznedar et al., 2000; Howard et al., 2000). Differences in hippocampal volume do not appear to be systematically related to age (Schumann et al., 2004).

Because of the prominence of the amygdala in some neurobiological accounts of

autism (discussed later), many studies have focussed on structural abnormalities within this brain region. In terms of overall size, again studies have found evidence of both larger (Howard et al., 2000; Sparks et al., 2002) and smaller (Aylward et al., 1999; Nacewicz et al., 2006) amygdalae in autism. Others have found no difference (e.g. Haznedar et al., 2000) and, as with whole brain volume, it has been suggested that differences in amygdala size are age-dependent, being present in children but not in adolescents (Schumann et al., 2004). There is some evidence of increased cell packing density in the amygdala in autism (Baumann & Kemper, 1985; Kemper & Bauman, 1993), although a more recent study failed to replicate this (Bailey et al., 1998).

Other brain areas in which structural abnormalities have been reported in autism include the STS, IFG and inferior parietal lobule. Hadjikhani and colleagues found reduced grey matter thickness in these areas, and found that this correlated with the severity of autistic symptoms (Hadjikhani, Joseph, Snyder & Tager-Flusberg, 2006).

A recent meta-analysis of 46 studies (Stanfield et al., 2007) found that several brain regions showed consistent evidence of enlargement in autism, including the cerebral hemispheres, cerebellum and caudate nucleus. Other areas, including the corpus callosum, were reduced in size but there was an overall increase in total brain volume in individuals with autism. Overall, this study found no difference in average amygdala size, but did find evidence of enlargement of the amygdalae in autism in younger age groups.

Autism has been described by some as a 'disorder of connectivity' (Minshew & Williams, 2007), and in some cases these findings of structural differences have been taken, together with findings from other imaging techniques, as evidence of differences in connectivity within and between regions. The smaller size of the corpus callosum in autism can be seen as evidence for reduced intrahemispheric connectivity (Piven, Bailey, Ranson & Arndt, 1997; Minshew & Williams, 2007). In contrast, there is evidence that short and medium range connections within the same hemisphere are more prevalent in autism (Herbert et al., 2004). Abnormal connectivity between regions has also been concluded from the findings of functional studies, based on the degree of correlation in the timecourse of activation of different cortical regions

(Friston, Frith, Liddle & Frackowiak, 1993). Examples include reduced functional connectivity between the amygdala and adjacent cortex during processing of facial expressions (Welchew et al., 2005), and reduced functional connectivity between extrastriate and superior temporal cortex during a mentalising task (Castelli et al., 2002).

1.3.3 Emotion recognition deficits in autism

Here I shall focus on the emotion recognition abilities of individuals with autism. The recognition of emotions in others is an important component of reciprocal social interaction. I shall first consider the evidence for an emotion recognition deficit in autism, and then examine the reported abnormalities in the processing of emotional stimuli.

One of the most common observations about people with autism is that they have problems interpreting the emotional states of other people. This has been backed up by empirical studies using tasks such as matching appropriate gestures, vocalisations, postures, contexts and facial expressions of emotion (Hobson, 1986b; Hobson, 1986a; Hobson, Ouston, & Lee, 1988a) matching facial expressions of emotion across different individuals (Hobson, Ouston, & Lee, 1988b), labelling facial expressions of emotion (Tantam, Monaghan, Nicholson, & Stirling, 1989; Bormann-Kischkel, Vilsmeier, & Baude, 1995; Wang, Dapretto, Hariri, Sigman, & Bookheimer, 2004), finding the 'odd one out' from a range of facial expressions (Tantam et al., 1989), and matching facial or prosodic expressions of emotion with verbal and pictorial labels (Lindner & Rosen, 2006). Caregivers commonly report that children with autism fail to recognise emotions, and empirical studies have shown that they fail to react to signs of distress in adults (Sigman, Kasari, Kwon, & Yirmiya, 1992; Bacon, Fein, Morris, Waterhouse, & Allen, 1998).

However, other studies have failed to find these deficits in emotion recognition (Ozonoff, Pennington, & Rogers, 1990; Buitelaar, van der, Swaab-Barneveld, & van der Gaag, 1999; Castelli, 2005), or have found that deficits are been restricted to particular emotions, such as surprise (Baron-Cohen, Spitz, & Cross, 1993) or fear (Howard et al., 2000; Pelphrey et al., 2002). Some studies have found deficits only

occur when the task is made more difficult, for example by only revealing the eye region of the face (Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997) or by pairing the images of faces with mismatching emotion labels (Grossman, Klin, Carter, & Volkmar, 2000).

These inconsistencies in the literature may be due to a number of factors. First, the composition of the autism group studied (children or adults, high functioning or low functioning), and the matching of autism and control groups (e.g. by verbal IQ or overall IQ) vary greatly between studies. Second, a wide range of different testing paradigms and stimuli have been employed, with each study typically using just one approach to measurement.

1.3.4 Emotion processing in the autistic brain

Whether or not there is a clear deficit in emotion recognition in autism, there is considerable evidence that emotional stimuli are processed differently in the autistic brain. In this section of the introduction I will again concentrate on the processing of facial expressions of emotion.

1.3.4.1 Salience of faces and gaze patterns

In autism, facial expressions appear to be viewed as less salient. Weeks and Hobson (1987) found that when children with autism were given a set of photographs that could be sorted either by facial expression or by the type of hat the person was wearing, children with autism were more likely than controls to ignore facial expression and sort according to hat type.

Additional evidence of abnormal face processing in autism comes from the study of gaze patterns. Normal adults show a very specific pattern of gaze when viewing faces, fixating mainly on the eyes, and other 'core features' – the nose and mouth (Walker-Smith, Gale, & Findlay, 1977; Luria & Strauss, 1978). Individuals with autism appear to exhibit abnormal patterns of eye-gaze, looking at these core features less often than do controls.

One of the first studies using eye-tracking in autism (Pelphrey et al., 2002) monitored

the eye movements of five adult males with autism and five controls whilst they performed a test of emotion recognition from photographs of facial expressions. The subjects with autism spent less time looking at the core features of the face (eyes, nose and mouth; subsequent analysis showed this effect to be driven by time spent looking at the eyes and nose). Also, when gaze data were analysed in terms of fixations, fewer of the autism group's fixations were to these core facial features. Similar results were found in a neuroimaging study by Dalton et al. (2005). Subjects completed two tasks, whilst their eye movements were monitored, and brain activity was recorded using fMRI. Task 1 involved discriminating between emotional and neutral facial expressions. Task 2 involved deciding whether a face was familiar or unfamiliar. The researchers found, in both tasks, fewer fixations to the eye region in the autism group, but no differences between the autism and control groups in the number of fixations in general, or in the fixations to the mouth.

Eye-tracking can also be used with video clips, as exemplified by a study by Klin and colleagues (Klin, Jones, Schultz, Volkmar, & Cohen, 2002), who studied the fixation patterns of 15 young males with autism, and 15 controls, while they watched film clips featuring characters engaged in social interaction. The subjects were not given any specific task, but simply had to watch the video clips. In contrast to static photographs of single individuals, these video clips are more 'ecologically valid' stimuli, in that they simulate a real-life social situation in which there are multiple distracting people and objects in the scene. Klin et al. found that, as with still photographs (Pelphrey et al., 2002; Dalton et al., 2005), the autism group looked less frequently at the eyes of the characters. In contrast, they looked more frequently at the mouths and bodies, and at other objects in the scene (Klin et al., 2002b).

A limitation to studying fixation patterns is that it can only indicate which information is available to the brain, not how the brain uses that information. For example, even if an individual shows normal fixation of the eyes, they may not make use of the information available in the eyes. Spezio et al. (Spezio, Adolphs, Hurley, & Piven, 2007a) used eye-tracking together with a novel method of presenting stimuli, to investigate which parts of the face subjects were using to recognise emotional expressions. Using the so-called 'bubbles' method (Gosselin & Schyns, 2001), they created images in which only certain parts of the face were visible. They found, like

Klin et al., that subjects with autism made more fixations to the mouth, and that this group had a greater reliance on information from the mouth in order to identify the emotion.

A recent study extended the use of eye-tracking to the relatives of individuals with autism. Dalton et al. (Dalton, Nacewicz, Alexander, & Davidson, 2007) measured fixation patterns in 12 individuals with autism, 10 of their siblings and 12 controls, whilst they looked at photographs of faces. They found that both the subjects with autism and their siblings made fewer fixations to the eyes. This finding suggests that abnormal fixation patterns might form part of the Broad Autism Phenotype discussed in section 1.3.1 of this thesis, and might thus be useful in the search for genes involved in the development of autism.

It is important to note that some studies of individuals with autism found no difference in gaze patterns (van der Geest, Kemner, Camfferman, Verbaten, & van Engeland, 2002; van der Geest, Kemner, Verbaten, & van Engeland, 2002; Dapretto et al., 2006). The reason for the difference between these and other findings is unclear, though the two studies that found no difference involved children, whereas the majority of studies which have found a difference in gaze behaviour have involved adult participants (but see Dalton et al., 2007). One possible explanation is that aversion to looking at the eyes, which commonly reported by adults with autism (personal observation), arises from the increasing complexity of social encounters in adulthood. However, the finding of eye-gaze abnormalities even in very young individuals with autism (e.g. Klin & Jones, 2008) suggests that these in fact arise early on in development, and that the failure to find deficits in some studies may be due to a lack of power in the study design.

To summarise, despite some negative findings, most studies have shown that individuals with autism look at social stimuli differently, in particular looking less at the eye region of the face (Pelphrey et al., 2002; Dalton et al., 2005; Klin et al., 2002b). With regard to the mouth region, some studies have found reduced fixation (Pelphrey et al., 2002), some increased fixation, (Spezio et al., 2007a; Klin et al., 2002b) and others no difference (Dalton et al., 2005). The reasons behind this are unclear, but the matching of the autism and control groups might be an important

factor, as might the ways in which the data are processed e.g. whether analysed in terms of fixations, and if so, which criteria are used to define a fixation point.

1.3.4.2 Patterns of brain activity

When viewing emotional facial expressions, individuals with autism also show unusual patterns of brain activity. Critchley et al.'s (2000) fMRI study of adults with autism found that this group showed less activity in the fusiform gyrus compared to controls. This effect did not depend on whether the subjects were performing an explicit emotion recognition task or a gender judgement task. Similarly, Hubl et al. (2003) found a reduced fusiform response in their autism group during emotion and gender processing tasks using facial expressions. Wang et al. (2004) also found reduced fusiform activity in children with autism when matching facial expressions of emotion, though not when labelling the same facial expressions. Dalton et al. (2005) found a reduced fusiform response in their autism group when judging the emotions of facial expressions. This reduced fusiform response in autism appears to persist even after specific training in facial emotion recognition (Bolte et al., 2006).

There is some evidence that pars opercularis of the IFG which, as discussed earlier, forms part of the mirror neurone system (MNS) in humans, is not active when children with autism view facial expressions. Dapretto et al. (2006) looked at brain activity in a group of children with autism and typically developing controls while they observed or imitated facial expressions. They found that whereas control children showed strong activity in this area, the autism group did not. The implications of this are discussed in the subsequent section of this introduction.

Some brain areas, such as the precuneus (Wang et al., 2004) and the peristriate visual cortex (Critchley et al., 2000), appear to show greater activity in subjects with autism, in response to facial expressions of emotion. There is less of a clear picture with respect to differences in amygdala response, with some studies finding reduced activation in the amygdala in subjects with autism compared to controls, when viewing whole faces (Critchley et al., 2000; Ashwin, Baron-Cohen, Wheelwright, O'riordan, & Bullmore, 2007) or just the eye region of faces (Baron-Cohen et al., 1999), but a recent study showing an greater amygdala response compared to controls (Dalton et al., 2005).

1.3.4.3 Interpreting abnormal brain activations

It is unclear how these findings should be interpreted in the light of behavioural data, including emotion recognition performance and the results of eye-tracking studies. One problem is how to infer a causal relationship between abnormal brain activity and abnormal behaviour, for example how to tell whether abnormal activity in a particular region is a cause of abnormal gaze behaviour, or a consequence of the different visual input that arises from this gaze behaviour.

As described earlier, the lack of response in the IFG pars opercularis is significant as it is the likely location of at least part of the MNS. However, it should be noted that while the MNS may be important in imitation (e.g. Iacoboni et al., 1999), studies seeking to demonstrate the role of an area in emotion recognition generally include explicit emotion recognition tasks, which Dapretto et al.'s (2006) study did not. Additional studies are needed to confirm whether this failure of individuals with autism to recruit the MNS in imitation also extends to emotion recognition tasks. Williams, Whiten et al. (2001) propose that a failure of proper development of the MNS could even play a causal role in the development of autism. They postulate that failure of the MNS could impair the development of proper 'self-other' representations, which would in turn lead to a deficit in Theory of Mind, and impaired reciprocal social interaction and social communication abilities.

The diminished fusiform activity observed in autism during emotion recognition or other face-based tasks (e.g. Critchley et al., 2000) could be due to this region's sensitivity to stimuli with which the subject has some degree of experience and expertise (Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999). Differences in fusiform gyrus response in autism may therefore be due to these individuals having less experience with faces. In support of this is the finding that even at a year old, children with autism pay less attention to faces than their typically developing counterparts (Osterling, Dawson, & Munson, 2002). This study looked at the home videotapes of the first birthday parties of children later diagnosed with autism. These children looked at other people less frequently than comparison children who were free from diagnosis, or children later diagnosed with mental retardation.

The unresolved issue is the reason for this lack of interest in faces. One possibility is that this is due to abnormal functioning of the amygdala. The idea that the social cognitive deficits of autism arise from abnormal amygdala function is well documented (Baron-Cohen et al., 2000). Evidence for this comes from a number of sources, including patterns of unusual activation in functional imaging studies. There is also the evidence of structural abnormalities in the amygdala, as discussed earlier. A recent study showed that a larger amygdala at age 3-4 tended to predict poorer social and communication ability several years later (Munson et al., 2006). The fact that the social and communication deficits manifest in autism appear to be associated, at least in children, with larger, rather than smaller, amygdalae, has led some to hypothesise that the amygdalae in autism are functioning abnormally due to incomplete 'neuronal pruning', which would take place as part of normal brain development (Howard et al., 2000; Eigsti & Shapiro, 2003; Frith, 2003). Thirdly, the deficits shown by individuals with autism in face processing are similar to those experienced by amygdala lesion patients (Howard et al., 2000; Adolphs, Sears, & Piven, 2001). It is notable that Howard et al.'s study found evidence of enlarged amygdalae in the autism group.

Evidence that these amygdala abnormalities in autism might have an impact on eye fixation patterns comes from the amygdala lesion patient SM, who shows a reduced tendency to look at the eye region of faces (Adolphs et al., 2005), which extends to face-to-face social interaction (Spezio, Huang, Castelli & Adolphs, 2007). The idea could also be supported by the findings of Dalton et al. (Dalton et al., 2005). This group showed that amygdala activity correlates with extent to which people with autism look at eyes. However, it should be noted that Dalton et al. have not interpreted their data in this way, and their alternative explanation for the reduced gaze fixation seen in autism will be discussed later.

A common explanation linking amygdala function to behavioural data is the idea that the amygdala is responsible for marking out stimuli such as faces and eyes as emotionally salient (Schultz et al., 2000; Grelotti, Gauthier, & Schultz, 2002). If this does not occur in the developing brain, the child will not seek out these features in his or her environment, and thus not gain the normal level of experience with them. This explanation fits with earlier claims of diminished salience of emotional faces in

autism (Weeks & Hobson, 1987). The amygdala is well placed for a direct role in the development of cortical expertise, with dense neural connections to the STS region, and to the ventral temporal cortex, where the fusiform gyrus is located (Aggleton, 1993).

An alternative explanation is that the amygdala does not play this causal role in patterns of eye fixation. Dalton et al. (2005) suggest that the correlation between eye fixation time and amygdala activity is in fact because fixation of the eye region is causing the amygdala activation. They propose that this is because individuals with autism find emotionally salient stimuli like eyes hyper-arousing, and that this in turn leads to eye and face avoidance. This role of the amygdala in generating an arousal response fits with its known involvement in detecting potential threat, based on the findings of animal studies (Amaral, Bauman, & Schumann, 2003). It provides an alternative explanation for the seeming lack of attention to faces seen in children with autism (Weeks et al., 1987). However, Dalton et al. do not offer an explanation of how or why this hyper-arousal occurs.

This study highlights the problem with trying to infer a causal relationship between imaging data and behavioural data, as a correlation in activity can be interpreted in either causal direction. Dalton et al.'s finding of a correlation between amygdala activity and gaze fixation could equally well be interpreted as evidence for the amygdala driving the subject to look at the eyes. In support of their alternative explanation is their finding that the amygdala is more highly activated in response to faces in subjects with autism than in controls. However, more data are needed to support this explanation, namely a replication of the enhanced amygdala response in subjects with autism, and alternative measures of arousal, in addition to the amygdala BOLD response.

Dalton et al. also propose that the fusiform hypoactivation seen in the autism group is a direct result of diminished gaze fixation, rather than due to a lack of expertise with faces. This is supported by the finding that the eye region is the most important part of face in driving the fusiform response (McCarthy, Puce, Belger, & Allison, 1999). This highlights the need to control for differences in gaze fixation in functional imaging studies, in light of the evidence for unusual fixation patterns in the autistic population.

One such study, which made all participants fixate at the centre of each image, found no difference in the levels of fusiform activity between participants with autism and controls (Hadjikhani et al., 2004). It is probably simplistic to say that either abnormal gaze patterns or decreased expertise for faces is wholly responsible for the decreased fusiform response seen in earlier studies; it is likely that both factors play a role. Also, with the wide variations in symptomatology across the autistic population, and likely differences in the aetiology of the disorder, it is possible that these two factors could differ in their relative influence in individual cases.

1.3.4.4 Evidence from mimicry

Additional evidence for unusual facial emotion processing in autism comes from studies of mimicry. As mentioned earlier, we tend to unconsciously and automatically mimic the facial expressions of others (Dimberg, 1982). Recently, McIntosh and colleagues have shown that this automatic mimicry is absent in autism (McIntosh, Reichmann-Decker, Winkielman, & Wilbarger, 2006), despite a preservation of voluntary mimicry. As there is evidence that facial mimicry facilitates emotion recognition (McIntosh, 1996), this could explain the deficits in emotion recognition seen in autism. McIntosh et al. (2006) claim that automatic mimicry occurs alongside a rapid sharing of others' emotional states, which is therefore also likely to be absent in autism. This inability to automatically experience others' emotional states is likely to impact on later social development.

1.3.5 Emotion recognition and social interaction deficits

Although differences in face processing and emotion recognition in autism are interesting in their own right and may provide insights into the mechanisms of typical face processing and emotion recognition, they have primarily been studied in an effort to understand the social deficits that occur in autism. Kanner's original description of autism highlighted the social and emotional aspects of this disorder (Kanner, 1943). Across the autism spectrum, these social deficits range from a complete lack of interest in social interaction, and failure to develop peer relationships, to more subtle problems in interaction with others, such as with the appropriate use of non-verbal communication, or in understanding the intentions of others. Although these social impairments are varied in nature, it is likely that they reflect a common neurological

impairment, which could be accessed using controlled tasks such as the recognition of facial expressions of emotion, in conjunction with neuroimaging techniques.

It has been argued that the social deficits of autism comprise the only one of the triad of impairments that is unique to autism and rarely present in other disorders, whilst communication deficits, and patterns of repetitive behaviour or restricted interests are also seen in primary language disorders and disorders of mental retardation respectively (Schultz, 2005). These social deficits might thus provide the best clue to the neurobiological basis of this disorder. There is also evidence that the social deficits seen in autism may contribute to the other deficits associated with this condition, for example by interfering with language development. It is likely that the development of language is driven to some extent by social motivation, which is much reduced in individuals with autism (Klin, Jones, Schultz, & Volkmar, 2003). A child's capacity to understand others' mental states is also thought to be particularly important in driving language development (Bloom, 2004), which again would predict impaired language development in autism.

The overall degree of social impairment of a person with autism can be assessed using the Reciprocal Social Interaction (RSI) subscale of the Autism Diagnostic Observation Schedule (ADOS), an assessment instrument used for the diagnosis of autism and autism spectrum disorder (Lord et al., 2000). The RSI subscale assesses skills such as rapport building, turn-taking in conversation, and appropriate use of eye contact. It has been shown that an autistic individual's scores on the RSI subscale can be predicted by his or her pattern of eye gaze when viewing social scenes (Klin et al., 2002b). Also, RSI scores have been found to correlate with brain activity in subjects with autism viewing facial expressions of emotion (Dapretto et al., 2006). As emotion recognition is frequently used in studies of subjects with autism as a test of social cognition, there is a need for studies looking directly at how this ability relates to an individual's social interaction skills as measured by the RSI subscale.

1.4 Introduction to the experimental chapters, and predictions

The studies described in this thesis are concerned with the recognition of emotion. The most extensively investigated aspect of emotion recognition is the processing of the characteristic facial expressions of the basic human emotions. Since the advent of functional imaging, a number of brain regions have been implicated in the neural processing of these facial expressions. However, the precise function of these regions is still poorly understood.

The imaging study described in Chapter 3 of this thesis sets out to address this issue, and more specifically, to investigate the nature of representations of emotion in the amygdala and the fusiform gyrus. I use the technique of multivariate pattern recognition, combined with high-resolution fMRI, to investigate whether facial expressions of individual emotions are represented separately in these regions, in the fine-grained pattern of neural activity. I predicted that information contained in the voxel-by-voxel pattern of activity in both of these regions would encode the identity of the emotional stimuli presented.

The subsequent chapters are concerned with other, less extensively investigated, indicators of an individual's emotion. Chapter 4 describes the development of a set of stimuli designed to convey emotion through social movement patterns. I investigate whether these cues, when isolated, are sufficient to convey the impression of a particular emotion, by developing a test of emotion recognition from these stimuli, and administering it to a large epidemiological sample. I predicted that individuals would be able to perform reliably above chance on this test, indicating an ability to recognise emotion from social movement patterns alone.

Following this, I investigate the brain mechanisms involved in recognising emotion from these stimuli, in comparison to those involved in the recognition from other cues. Chapter 5 describes an fMRI study using these novel stimuli, together with facial expressions and non-verbal vocalisations. I predicted that certain components of the facial emotion recognition network would also be activated by movement cues to emotion, but that those involved purely in the sensory/perceptual processing of emotional faces, or indeed voices, would not be activated by these new stimuli.

In Chapter 6 I investigate the application of these stimuli to investigate emotion recognition in autism, a disorder characterised by its severe impact on social understanding. Recognition of facial expressions of emotion in autism has been extensively investigated, with some inconsistencies in findings. I investigate the recognition of four basic emotions from facial expressions, and from social movement patterns. I predicted that because of the reliance of these new stimuli on social understanding, I would find a deficit in performance in the autism group in emotion recognition from social movement patterns, perhaps even in the absence of any deficit in facial expression recognition.

Finally, I investigate the impact of expertise with sensory cues on emotion recognition ability, returning once more to the processing of facial expressions. It has been shown that children with autism pay less attention to faces, and that adults with autism look less often at the eye region of the face. In Chapter 7 I investigate the impact of this on a face-processing task which relies on the eye region – the discrimination of genuine from posed smiles. I use eye-tracking to monitor participants' gaze during this test. I predicted that individuals with autism would look less often at the eyes of the face stimuli, and would be impaired in the discrimination of genuine from posed smiles.

Chapter 2 Methods

Both structural and functional MRI techniques, including data processing in SPM, are used in Chapter 3 and Chapter 5 of this thesis. In the study described in Chapter 3, the fMRI data collected are analysed using multivariate pattern recognition. The study described in Chapter 7 uses eye-tracking data. This chapter gives a detailed description of these methods. Before this, I give details of the recruitment and screening of participants.

2.1 Recruitment, screening and matching of participants

In all of the studies described in this thesis, participant testing was carried out by myself, except for the data for the large adolescent sample tested in the study described in chapter 4, which was collected by the ALSPAC team.

The studies described in Chapter 6 and Chapter 7 of this thesis included participants with autism, Asperger syndrome (AS), or autism spectrum disorder (ASD). These were recruited from a database of participants from previous studies, but were originally recruited from a variety of sources. Some were recruited from social groups set up for individuals with autism or AS. Others were recruited by advertisement in the National Autistic Society newsletter, the Autism London newsletter, the ASPEN message board (on the National Autistic Society website) and a website for university students with AS.

All participants had received a diagnosis of autism or Asperger Syndrome from a GP or other health professional, and prior to participation, this diagnosis was confirmed by administration of the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000). This is a standardised measure for the assessment of autism or autism spectrum disorder that which assesses ability in three domains: social communication, reciprocal social interaction (RSI), and imaginative use of materials. The ADOS comprises four modules, only one of which is administered. The module which is chosen depends on the language abilities of the individual being assessed. As all of the participants in this study were adults with fluent speech, module 4 was

administered. This takes the form of a semi-structured interview, with a series of questions designed to probe the person's social and emotional understanding, his or her ability to empathise, the understanding of social rules and norms, and the ability to communicate in a socially appropriate and flexible manner. There is also an optional set of questions about daily living (for example: 'Do you manage your own money?'), plus a set of tasks which test imaginative abilities.

The output of the ADOS is a score in each of these three domains, with a higher score indicating a greater degree of impairment. If the scores for the communication and RSI subscales are each above a certain cutoff, and in addition the sum of these scores is above a cutoff value, the diagnosis of autism is confirmed. Scores below this but above a second cutoff lead to a diagnosis of ASD. For the purpose of the studies described in this thesis, this second cutoff was used.

The studies in this thesis also involved participants without autism or other conditions – in the fMRI studies described in Chapter 3 and Chapter 5, the test-retest experiment in chapter 4, and as controls in the autism studies described in Chapter 6 and Chapter 7. These were recruited from a database of previous experimental participants, and also by advertisement online (at www.gumtree.com, a site used for finding casual work in London).

In the studies described in Chapter 6 and Chapter 7, the autism and control groups were matched for IQ by administration of the Wechsler Abbreviated Scale of Intelligence (WASI, Psychological Corporation, 1999). This is a modified, shorter version of the Wechsler Adult Intelligence Scale (WAIS), and consists of just four subtests: Vocabulary, Block Design, Similarities and Matrix Reasoning. Scores from the Vocabulary and Similarities subtests together give a measure of verbal IQ, whilst the Block Design and Matrix Reasoning scores are combined to give a measure of performance IQ.

All participants in all studies were screened for exclusion criteria – dyslexia, epilepsy and other neurological or psychiatric questions, by self report, prior to participation. All participants gave informed consent, and all studies in this thesis were approved by the local ethics committee.

2.2 Eye-tracking

The study of gaze behaviour has long been used to investigate how stimuli are processed. The premise behind this is that when a person looks directly at ('fixates') an object, its image falls on the fovea, the part of the retina specialised for detailed visual processing. The eyes therefore need to move in order to inspect the whole of a visual scene in detail (Norton & Stark, 1971). Recordings of gaze behaviour thus indicate where in a visual scene a person was seeking detailed information.

Simply filming subjects whilst they look at a picture or watch a video clip can give a crude indication of their gaze direction. More specialised equipment allows the direction of gaze to be determined more accurately. One technique is to use a 'scleral search coil' – a contact lens incorporating wire coils – in conjunction with a magnetic field around the subject's head. A less invasive approach is to illuminate the eye with an infra-red beam, and then capture the reflected image with a video camera. Provided that head movements are prevented, the position of the pupil provides sufficient information to determine where on a screen a subject is looking. However, it is also possible to capture the reflection from the cornea, in addition to the pupil. The relative position of these two points is more independent of head position, thereby requiring only modest restriction of head movements. In addition, novel techniques are under development which detect the position of the fovea directly, potentially allowing improvements in accuracy (Gramatikov, Zalloum, Wu, Hunter, & Guyton, 2007).

The temporal resolution available in the collection of eye-tracking data varies according to the type and model of eye-tracker used. Pupil-only and pupil-CR eyetrackers typically operate at sampling rates of between 50Hz (e.g. ASL R6 model; www.a-s-l.com) and 2kHz (e.g. SR Research Eyelink 2k; www.sr-research.com). Direct tracking of the fovea can be accomplished at speeds of up to 200Hz (Gramatikov et al., 2007). In general, higher temporal resolution is possible with head-mounted systems or scleral search coils, which are in direct contact with the eye. Spatial resolution varies from 0.005 degrees of visual angle (Clarke, Ditterich, Druen, Schonfeld & Steineke, 2002) to 0.5 degrees (ASL Model 310; www.a-s-l.com), or approximately 0.1 degrees for methods that involve direct detection of the fovea (Gramatikov et al., 2007).

As the various available eye-tracking systems vary in their spatial and temporal resolution, the system chosen will depend on the requirements of the experiment. Studying the timecourse of fast eye movements as saccades requires a higher temporal resolution. However, when studying clinical groups, or when combining eye-tracking with fMRI, a less invasive remote setup might be more appropriate, if this high temporal resolution is not needed, i.e. if simply studying the location of fixations.

Collected data are often processed to find the areas on which the subject 'fixated'. A fixation occurs when the observer looks at the same point for long enough to allow the processing of visual information from that point. Typically, if the point of gaze remains within 1 degree of visual angle for at least 100 milliseconds this is classified as a fixation (Norton & Stark, 1971), though some eye-tracking studies have used different criteria (e.g. Pelphrey et al., 2002).

In the study described in Chapter 7 of this thesis, an ASL (Applied Science Laboratories) R6 remote optics eye-tracker was used, which sampled eye position at a rate of 50Hz, and was connected to an ASL series 6000 control unit. An additional video camera was incorporated into the setup, together with software which tracked any head movements during the experiment, to ensure that the eye-tracking camera remained trained on the eye throughout. The data collected from the eye-tracker comprised a pair of values recorded every 20ms, which represented the x and y coordinates of the participant's point of gaze at that time. These data were analysed using MatLab, and the full procedure is described in chapter 7.

2.3 Structural and functional brain imaging using MRI

2.3.1 The principles of the MRI technique

Magnetic resonance imaging is made possible by the fact that hydrogen nuclei, which are abundant in the brain, have magnetic properties. This in fact applies not just to hydrogen, but to any element which has an odd number of protons in its nucleus. Each hydrogen nucleus is made up of just a single proton, which has a positive charge, and when it spins on its axis it creates its own tiny magnetic field. Normally, these are

aligned randomly with respect to one another, so there is no net magnetisation within the brain. However, when the brain is put in a large fixed magnetic field (known as B_0), the magnetic fields of the nuclei align themselves with the magnet's field. A small proportion of the nuclei align themselves against (antiparallel to) the magnet's field, but the majority are parallel to it. The magnetic field of a single proton can be represented as a vector – a mathematical entity that has both a size and a direction. The vector of an individual hydrogen nucleus is called its Magnetic Dipole Moment (MDM). The Net Magnetisation Vector (NMV) describes the overall magnetic field caused by the summed effect of the orientation of many protons.

When a pulse of energy is applied to the brain, the protons 'flip' out of alignment. For hydrogen nuclei, this energy needs to be supplied at the frequency of radio waves. The angle by which alignment is disrupted is called flip angle, and is normally 90 degrees. The axis in the scanner that runs parallel to the fixed magnetic field is known as the z-axis, so when the protons are flipped by 90 degrees, they are flipped into the x-y plane, or 'transverse plane'. The magnetic moments of the protons also start to rotate, or 'precess', in phase with one another, which causes the NMV to rotate around the z-axis, in the x-y plane. This movement induces an electric current, picked up by a 'receiver coil' placed over the head, which is the basis of the 'signal' collected from the MRI scanner.

When the energy pulse is switched off, the magnetisation in the x-y plane decays, and that in the z direction (parallel to B_0) recovers. Both of these processes occur gradually, and can take up to several seconds. Two time constants, T1 and T2, are used to describe the rate at which these processes occur. T1 is the time taken to recover 63% of the magnetisation in the z direction. T2 is the time taken for 63% of the magnetisation in the x-y plane to decay. The two processes occur independently of each other, and are driven by different mechanisms. Transverse (x-y) decay (termed T2 decay) occurs due to interactions between neighbouring hydrogen nuclei. Longitudinal (z) recovery (termed T1 recovery) occurs due to loss of energy from the nuclei to the surroundings.

2.3.2 Structural MRI

2.3.2.1 Obtaining contrast in the MR image

The aim of structural MRI is to produce an image in which there is good contrast between the grey matter of the brain (mainly cell bodies) and white matter (myelinated axons). This is possible in MRI because the rate at which T1 recovery and T2 decay occur depends on the environment surrounding the proton. Both of these processes occur more quickly in protons in white matter (which is mainly fat) than in grey matter (mainly water). This means that the signal given out by a proton depends on the tissue type it is in. The relationship between tissue type and signal depends on whether the signal is driven by the speed of decay or the speed of recovery, and this in turn is determined by the timing of the radio-frequency (RF) energy pulses, and also the timing of when the signal is read from the receiver coil (called the echo time, TE).

If the RF pulses occur relatively close together, protons in neither fat nor water will have time to recover fully from a pulse before the next one. However, more protons in fat will recover than those in water. This means that more protons in fat will be 'flipped' into the transverse plane by the next RF pulse, and a stronger signal will be given off by the fat, which will appear bright on the resulting image. This is known as a T1-weighted image, as it is driven by the rate of T1 recovery of the protons.

In contrast, in order to make an image which is dominated by the rate of T2 decay, the RF pulses must occur at a lower rate, to allow full recovery of protons in both fat and water. The differential signal between fat and water is achieved by adjusting the echo time (TE). The TE must be long enough that protons in both fat and water have some time to decay. Protons in fat will have decayed more than those in water, so a stronger signal will be given off by the water, which will appear bright on the image. This is known as a T2-weighted image.

2.3.2.2 Encoding position in the MR image

In order to create a 3-dimensional MR image from the signal that is collected from the scanner, it is necessary to know which parts of the signal come from which spatial location in the brain. This is achieved through using magnetic field gradients, in

which the magnetic field varies linearly according to the distance along a particular axis. Three such gradients are applied at particular time-points during the scanning, along the x, y and z-axes. These gradients allow the signals from different parts of the brain to be distinguished, because of the fact that the frequency at which a proton's MDM precesses about its axis depends on the strength of the magnetic field that it is in, so applying a gradient causes the precessional frequency of the protons to vary along the axis of the gradient.

The 'slice select' gradient is applied along the z-axis, which runs parallel to the main magnetic field B_0, and in the 'head to foot' direction when the subject is lying in the scanner. Applying this gradient means that all protons lying in a particular x-y plane will have the same precessional frequency as one another, and different from that in other x-y planes in the brain. This is important because when the RF (radio frequency) pulse is applied, only those protons with a precessional frequency equal to the frequency of the RF pulse will be 'flipped' by the pulse. This means that for a given gradient and a given RF frequency, signal will be collected for only one x-y 'slice' in the brain. The RF frequency or the gradient can then be altered to collect signal from the next slice, and so on.

The gradients applied in the x-direction (from ear to ear) and the y-direction (from the nose to the back of the head) are used to allow the localisation of the signal within each slice. The gradient along the x-axis is called the frequency encoding gradient. It is applied at the time when the signal from the scan is being read. It alters the precessional frequency of protons depending on their position on the x-axis, and therefore alters the frequency of the signal which is given out by these protons and picked up by the receiver coil. The resulting signal picked up by the coil comprises a complex waveform that can be broken down by Fourier analysis (Fourier, 1822) into a number of components, each with a particular frequency and a particular amplitude. The amplitude of the component with the lowest frequency corresponds to the strength of the signal coming from protons at one end of the x-axis. The amplitude of the next component corresponds to the signal from protons a little further along the x-axis, and so on.

The remaining gradient, applied in the y-direction, is called the phase encoding

gradient. This is applied after the RF pulse, but before the signal is read, for a very brief duration. Before this gradient is applied, the MDMs in the slice are all precessing in phase with one another as a result of the RF pulse, i.e. the vectors are all pointing in the same direction in the x-y plane at any given point in time. The brief application of the phase encoding gradient temporarily changes the precessional frequency of the protons in this slice, according to their position on the y-axis. After the gradient is removed, the protons revert to their original frequency, but because they have been precessing at different frequencies for a short while, they are no longer in phase with one another. The precise phase of a proton will depend on its position on the y-axis. The phase of the components of the signal collected during the scan can be decoded to determine which spatial location each component of the signal is from.

2.3.3 Functional MRI

In functional MRI (fMRI), the MRI technique is used to measure the level of activity across the brain, rather than fixed structural features. In fMRI studies, two principles of brain organisation are important – functional specialisation and functional integration. Functional specialisation describes the idea that different cognitive and perceptual processes are physically separated in the brain, in that they occur in specialised, anatomically separate neural structures. A clear example of this is seen in the separate areas of visual cortex specialised for colour and motion vision respectively.

The concept of functional integration is based on the premise that these different specialised areas have extensive connections with one another, and thus can interact and influence one another. These processes are investigated in studies of connectivity. The term functional connectivity describes the correlations that occur in the activity of two or more brain regions, regardless of how these correlations come about. In contrast, measures of effective connectivity are designed specifically to probe the influence one neural system has over another (Friston, 1994).

2.3.3.1 How brain activity is imaged using MRI

In contrast to structural MRI, in which a single, high-resolution image is taken of the brain, fMRI involves taking many fast, low-resolution images, one after the other, to

enable the measurement of changes over time. MRI is used to measure neural activity via its effect on blood flow, and the level of oxygen in the blood. An increase in neural activity results in an increased demand for glucose and oxygen, which is met by an increase in local blood flow (Ogawa et al., 1992). The signal measured in fMRI is therefore termed the Blood Oxygen Level Dependent (BOLD) signal.

2.3.3.2 The biological basis of the BOLD signal

The use of MRI to measure blood flow in the brain is only possible because the oxygenated and deoxygenated forms of haemoglobin (known as oxyhaemoglobin and deoxyhaemoglobin) have different magnetic properties. Deoxyhaemoglobin is paramagnetic, i.e. is magnetically susceptible, whereas oxyhaemoglobin is not. The impact of this is due to an additional process affecting the signal in the receiver coil, known as T2* decay. T2* decay is primarily due to inhomogeneities in the magnetic field strength in the brain tissue. These affect the speed with which the magnetic moment of a proton rotates (precesses) around axis of the main longitudinal magnetic field. As a proton moves through regions with slightly different field strengths, its precessional frequency will change, and it will no longer be in phase with other protons, causing a loss in signal in the transverse plane (dephasing).

Dephasing occurs faster in an environment rich in deoxyhaemoglobin. Protons surrounded by deoxyhaemoglobin will be much more susceptible to T2* decay than those surrounded by oxyhaemoglobin (Ogawa et al., 1992).Therefore, brain regions with a large amount of oxygenated blood will give off a greater signal than those with more deoxygenated blood. The relationship between blood oxygenation levels and neural activity, however, is less straightforward. Counterintuitively, more active brain regions give off a greater signal, indicating a greater level of oxygenation of the blood. This is because when a brain region is more active, the blood flow to it increases disproportionately, so more extra oxygen is provided than is needed by the active brain tissue. Therefore, there is more oxyhaemoglobin and less deoxyhaemoglobin in that area than in the surrounding areas, and the signal is greater.

2.3.3.3 The design of imaging experiments

In a functional imaging study, brain activity is measured under particular experimental conditions, normally in order to find the brain area activated by a

particular process of interest. The experimental conditions must be chosen carefully in order to isolate this process. The simplest type of design is subtraction-based. An example of this is if a subject is scanned whilst doing two tasks: task A and B are identical in every way, except that task A involves the cognitive process of interest, whereas task B does not. The brain activity resulting from task B is subtracted from that from task A, in order to isolate the brain regions specific to the process of interest. A problem with this approach is that it relies on the assumption of pure insertion – that the insertion of the process of interest into the task does not affect in any way the other components of the task, and the brain activity that results from them, whereas in reality, it is possible that existing components will interact with the inserted component (Friston et al., 1996).

An extension of the subtraction-based approach is the use of conjunction analysis (Price & Friston, 1997). This type of design includes multiple pairs of conditions, each designed to isolate, by their subtraction, the same process. The brain areas common to all subtractions are assumed to be those involved in the process of interest. This approach avoids making the assumption of pure insertion, made in a simple subtractive experiment, as any brain areas activated by the interactions between existing and inserted processes will not be common across the subtractions when they are combined. A conjunction analysis tests the null hypothesis that at least one of the contrasts included in the conjunction does not activate the voxel in question; thus, the only voxels activated by the conjunction are those activated in all of the contrasts. Early methods of conducting a conjunction analysis (Friston et al., 1999a, 1999b) were less stringent, as they instead tested the null hypothesis that neither of the contrasts activated the voxel significantly. This has since been termed the 'global null hypothesis' (Nichols et al., 2005). The conjunction analysis described in Chapter 5 of this thesis was based on a test of the more stringent 'conjunction null hypothesis'. Using this method, a significant result requires that all of the comparisons included in the conjunction are also significant individually, for the voxel in question.

An alternative to a subtraction–based design is a factorial design. This involves two or more factors, each of which has more than one level. For example, a 2x2x2 factorial design includes three factors, each of which has two levels; a 2x4 factorial design has two factors, one with two levels and one with four. The results of such a study can be

analysed to look at the effect of each factor individually on brain activity (analysis of main effects). However, the main strength of this type of design is that one can investigate the effect on neural activity of an interaction between two or more factors. This means looking for brain areas in which the effect of factor 1 on the area depends on the status of factor 2. For example, in the fMRI study described in Chapter 5, I looked at interactions between the factor Emotion (emotional versus neutral stimuli) and Task (emotion recognition versus control task). If activity in a brain area was associated with an interaction between these factors, this would indicate that the effect of an emotional stimulus on its activity was dependent on whether the subject was paying attention to emotion.

The design described above is categorical, in that there are only two alternative levels for each factor. An alternative to this is a parametric design, in which multiple levels of a factor are used. This is useful if there is reason to expect the relationship between this parameter and brain activity to be non-linear. The different values of the parameter can be built into the experimental design (eg levels of red in an image), or can be determined after the experiment, (eg the subject's accuracy level on the experimental task could be used as a parameter). Post-hoc manipulation of the data to allow this type of parameter is a strength of the fMRI technique, though it is only possible in event-related designs (see below).

Another way in which fMRI study designs differ is in how the different experimental conditions are spaced within the experiment. Studies can be of two types: blocked and event-related. In a blocked design, there are multiple consecutive repetitions of a particular experimental condition, e.g. multiple presentations of a stimulus, or requests for a task to be performed. This is followed by blocks of one or more alternative conditions, and in some designs, baseline blocks, which typically have no stimulus or task, and are incorporated to allow the BOLD signal to decay prior to the next block. The block approach is effective, because the BOLD response, and thus the fMRI signal, evoked by a single stimulus presentation is very small. With multiple presentations, the signal size increases. This maximises the variability in the signal which is due to the stimulus, and thus increases the statistical power of the design (Aguirre & D'Esposito, 2000).

However, not all experimental questions can be answered using a blocked design. One disadvantage of this design is that it is predictable, so the subject knows what type of stimulus is coming next. This can make studying the effects of a task difficult – for example, if the subject has to identify the stimulus present, and each stimulus is identical to the previous one, the subject effectively has no task to perform. Oddball paradigms, which specifically measure the response to an infrequently occurring stimulus, are not conducive to a blocked design. Similarly, in some studies the experimenter may wish to group and analyse trials post-hoc, based on the subject's responses, e.g. separate out correct and incorrect responses. This can not be achieved with a blocked design.

The alternative approach, which is used in these circumstances, is an event-related design. In this design, trials of the different types occur in a random or pseudorandom order. This is possible because stimuli only need to be of relatively short duration to produce a change in the BOLD response (Donaldson & Buckner, 2001), so short stimuli do not need to be grouped together with others of the same type to produce a signal. Another important property of the BOLD response is that successive BOLD responses sum approximately linearly (Donaldson et al., 2001). This means that if two stimuli or conditions occur close together in time, although the resulting BOLD responses overlap, they can be separated mathematically. A disadvantage of event-related designs is that although manipulations can be applied to enhance power by increasing the variability in the stimulus-induced signal, they are still inherently lower in power than blocked designs, as the BOLD response to a single stimulus presentation is fairly small (Aguirre et al., 2000).

2.3.3.4 Processing of fMRI data

Prior to analysis to examine the effects of experimental manipulations, fMRI data need to be pre-processed. The fMRI data collected in Chapter 3 and Chapter 5 of this thesis were realigned and unwarped, spatially normalised, and smoothed. The multivariate analysis of the data collected in Chapter 3 was performed on the normalised but unsmoothed data.

2.3.3.4.1 Realignment

Realignment, also called motion correction, allows for movement of the subject

during scanning. This is important as movement can cause artefacts in the BOLD signal – a change in the signal measured from a particular location within the scanner could arise from activity in the brain region at that location, or could arise simply because the subject has moved, and a different brain region now occupies that location (Ashburner & Friston, 2003b). This is a particular problem if the movement is correlated with the different conditions in the experiment, which can happen, for example, if the task in the scanner involves making hand movements. The changes caused by subject movement need to be accounted for before those caused by brain activity can be examined. Realignment involves estimating how much the brain has moved (in the 3 different possible directions of translation, and 3 different possible directions of rotation) between each successive scan and a reference scan (usually the first scan, but sometimes the mean of all scans). This is done by finding the values of these 6 parameters that minimise the differences in signal between each scan and the reference scan, in an iterative process. The brain is treated as a rigid body, so stretches or shears are not applied. Even after this simple realignment, a lot of the remaining variation in the signal is still caused by movement, as movement in one scan can affect the signal in subsequent scans. This remaining variation must be removed by the application of a mathematical adjustment.

2.3.3.4.2 Unwarping

Unwarping is another part of correcting for movement during scanning. It is necessary because of small inhomogeneities in the magnetic field which distort the image. When the subject moves, the relation of these distortions to the movement is non-linear (Andersson, Hutton, Ashburner, Turner, & Friston, 2001). However, if the relationship between the movements and the change in distortion is known, then the movement parameters estimated during the realignment stage can be used to correct for these distortions, or 'unwarp' the brain images.

The unwarping of the data can also be performed using field maps collected at the time of scanning. These can give improved accuracy during the unwarping process, as they measure directly the inhomogeneities of the magnetic field within the brain. They are most accurate if the subject does not move at all between the acquisition of functional data and the acquisition of the field map, so that the field map is an accurate measure of the actual inhomogeneities present when the functional data was

collected. Head movement in between functional and field map data collection leads to distortions that can not be corrected for so easily (Hutton et al., 2002).

2.3.3.4.3 Spatial normalisation

Spatial normalisation is necessary in order to be able to compare or combine activations across scanning sessions, and across subjects, as different brains are slightly different in size and shape. After normalisation, a particular voxel will correspond to the same structure in one brain as in another. Normalisation involves warping the brain images acquired so that they occupy a standard space that is the same for each subject. The activations are then plotted on this standard brain. In the studies reported in chapters 3 and 5, the images were normalised to the template brain from the Montreal Neurological Institute, which is derived from 305 different brains (Evans, Kamber, Collins, & MacDonald, 1994), and based on the coordinate system described by Talairach and Tournoux (1988). In the normalisation process, a combination of 12 different transformations in varying degrees is applied to the brain image to minimise the difference between it and the target brain – 3 translations (in the x, y and z directions) 3 rotations, 3 shears and 3 zooms. As with realigning, this is achieved by an iterative process. The end result is brains that are matched in terms of size and shape, but not necessarily matched at the level of individual sulci (Ashburner & Friston, 2003a).

2.3.3.4.4 Spatial smoothing

After normalisation, functional images are smoothed, using a Gaussian filter. This means that the signal in each voxel is adjusted, to make it more similar to the signal from the neighbouring voxels. The influence that each of the neighbouring voxels has depends on the shape of the 'filter' used to smooth or 'convolve' the data. A Gaussian filter is shaped like a 3-dimensional normal distribution, such that a voxel's closest neighbours will have a greater influence on its final value than those voxels further away. Such filters, or kernels, vary in size. The size of a Gaussian filter is described by the unit of Full Width Half Maximum (FWHM), which is the width of the filter at a height which is half the maximum height. In this case, a filter of FWHM 6mm was used, in the studies described in Chapter 3 and Chapter 5 of this thesis.

An advantage of smoothing is that it increases the signal-to-noise ratio of the data.

This because the information in the BOLD signal, being dependent on blood flow, is present over a spatial scale of a few millimetres, whereas any noise present in the data generally has higher spatial frequencies than this, as it is independent for each voxel. Smoothing also helps to make the data more suitable for subsequent statistical analysis, by making them more normally distributed (Smith, 2001).

Smoothing is also important when data are to be averaged across many subjects, as it ensures that data are analysed at a spatial scale that is meaningful. On a very small spatial scale, subjects are likely to differ considerably in their functional anatomy, as aspects of organisation at this level are specific to the individual, and not shared with others.

The study described in Chapter 3 of this thesis used both univariate and multivariate analysis. The data for the multivariate analysis were not smoothed. This is because multivariate analysis operates at the level of individual voxels, so the fine-grained spatial information needs to be preserved. In addition, in multivariate analysis, data are not combined across subjects – individual subjects are analysed separately, so the analysis gains no advantages from smoothing in this respect.

2.3.3.5 Analysis of fMRI data using SPM

Typically, fMRI data are analysed with a view to determining which brain regions were activated during particular experimental conditions. The technique of Statistical Parametric Mapping (SPM) runs the desired analysis on each individual voxel separately, in what is known as a mass univariate approach (Friston et al., 1995). Analysis in SPM is based on the General Linear Model (GLM), a statistical model that forms the basis of t-tests, f-tests, linear regression, and analysis of variance (ANOVA), amongst other tests (Friston et al., 1995). The GLM approach involves constructing a model of the form expressed in the formula $Y = X*B + E$. It is based on an attempt to explain observed data, Y, in terms of the influence of one or more variables X. That which can not be explained in terms of these variables is termed residual variation, noise, or error (E). B represents one or more parameters, that describe the extent to which each variable accounts for the variation in the data (Y). SPM involves estimating the value of these parameters for each voxel in the brain.

Because fMRI data comprises values for each voxel, with each voxel imaged many times over, the data of interest, Y, is contained in a matrix, with a column for each voxel of the brain, and a row for each 'measurement', or 'volume', i.e. the data collected over one scan of the entire brain. X is also a matrix, with as many rows as there are variables of interest, and the columns showing the values of each of these variables during each volume. These variables are termed predictor variables, and X is known as the design matrix. B is termed the parameter matrix, and E is a matrix of error terms.

The design matrix, X, is constructed to take account of the timecourse of the BOLD response in the brain. Usually, the value of a variable of interest, such as the presence of a particular stimulus, will be 1 in some volumes (when the stimulus was present) or 0 in others (when the stimulus was absent). However, the BOLD response does not 'switch on' as quickly as a stimulus does, but instead takes time to build up and time to decay. The design matrix is therefore multiplied or 'convolved' by the pattern of a typical BOLD response to allow for this. This is termed 'modelling' the BOLD response.

After modelling the BOLD response, the next stage in SPM is parameter estimation. For each predictor variable, the value of the parameter associated with it is calculated, such that the modelled BOLD response best fits the observed data, Y. This is done separately for each voxel.

The next step is to measure the significance of the size of the parameters, or combinations of the parameters, for each voxel, by comparing the variance in the data that these parameters explain, with the remaining unexplained variance. Combining the parameters allows the testing of particular experimental hypotheses for each voxel. For example, to test the hypothesis that a voxel is activated more strongly in one condition than in another, the parameters are estimated for each of these predictor variables, and the difference between these parameters is compared to the error, to see whether it explains a significant proportion of the variance in the data. The end result of this hypothesis testing is a separate t-value for each voxel, for each combination of predictor variables. These t-scores can then be converted into Z-scores. The resulting parameters can be plotted into the anatomical space of a standard brain, to give a so-

called Statistical Parametric Map.

The final stage in data analysis is assessing which of the voxel activations are statistically significant. The difficulties surrounding this arise from the fact that analysis by SPM is massively univariate, in that a separate t-value is calculated for each of several thousand voxels. Typically, the cutoff probability in a single t-test might be 5%, meaning that if the null hypothesis were true, there would only be a 5% chance of obtaining that t-value. However, if a test such as this is performed on a large number of voxels, the chance of finding at least one 'false positive', or making a type I error, increases in proportion to the number of voxels tested. This overall probability of finding a false positive is known as the 'family-wise error' (FWE), and should be kept as low as possible, ideally below 5%.

In conventional statistics, the normal way to circumvent this problem is to apply a Bonferroni correction, which raises the threshold necessary for a significant result, by dividing the cutoff p-value by the number of tests performed. However, in SPM, such a large number of tests are performed that reducing the p-value in this way would mean missing a large number of genuine activations, i.e. making a type II error, due to the loss of statistical power (Nichols & Hayasaka, 2003). The Bonferroni correction is in fact too stringent a correction for applying to voxel activations, as it assumes that the voxels are independent of one another, whereas in fact the signals in adjacent voxels are correlated with one another.

An alternative way to keep family-wise error low, without losing too much power, is to only consider voxels if they are part of a cluster of voxels that are active, rather than highly active but solitary voxels. This approach works because it is unlikely that a large number of adjacent voxels would be simultaneously active purely by chance. However, it means that small but genuine areas of activation will necessarily be missed. Also, adjacent voxels may be made more similar in activation level by smoothing, rather than by similar levels of BOLD signal.

Another alternative is False Discovery Rate (FDR) correction. Unlike Bonferroni correction, this does not correct to maintain the overall family-wise error rate, but instead maintains a particular rate of false positives relative to the total number of

activations – so, for example, a threshold of 5% would mean that 5% of all significant activations would be false positives. This is achieved by looking at the distribution of the Z-scores of the voxels, to determine the amount of signal present, and adjusting the sensitivity of the threshold accordingly (Genovese, Lazar, & Nichols, 2002). This approach was used in the univariate analysis of fusiform responses in the study described in Chapter 3, and in all analyses of fMRI data in Chapter 5, with the exception of the conjunction analysis. As discussed earlier, a very conservative method of conjunction analysis was adopted, so p-values were reported uncorrected in this instance.

An alternative way of applying FWE or FDR correction is to use it over a small region only (small volume correction), rather than the whole brain. This 'region of interest' (ROI) approach is useful if one is only interested in activations in one particular brain region, based on an *a priori* hypothesis. The correction applied to the p-values is based on the total number of comparisons within this region of interest, rather than within the entire brain. This approach was used in the univariate analysis of the BOLD response in the amygdala in Chapter 3.

2.4 Multivariate pattern recognition

Mutivariate pattern recognition, or statistical pattern recognition, is a way of analysing fMRI data in terms of the pattern of activity across a number of voxels. In conventional methods of fMRI analysis (such as Statistical Parametric Mapping as described in section 2.3.3.5), data from each voxel are analysed individually. Statistical tests are performed to see if the variables manipulated in the experimental design (for example the visual stimulus displayed) can explain the variation in the BOLD signal from that voxel over time. These tests are performed individually for each voxel, in what is termed a mass univariate approach.

In contrast, multivariate methods of analysis take as their input the raw BOLD signal from a number of voxels (Kamitani & Tong, 2005). As the voxels are analysed together, weak information from many voxels can be combined, which might not reach statistical significance if the voxels were analysed individually. For this reason, the multivariate technique is more sensitive. Also, information about the activity of

one voxel in relation to the activity of another is preserved in multivariate analysis, in contrast to the univariate approach. Preprocessing steps such as spatial smoothing of the BOLD signal are not used in multivariate analysis, in order to preserve the information available in the spatial pattern of activity. Because of the increase in sensitivity, more information can potentially be obtained from a smaller number of repetitions, perhaps leading eventually to almost real-time measurement of neural activity (Haynes & Rees, 2006).

The aim of multivariate analysis is not, as with conventional analysis, to localise a function (such as colour perception) to a particular brain region. Instead, it is typically used to see whether activity in a specifically selected brain region can be measured and used to predict a mental event, such as what the subject was thinking or planning at that time. It can also be used to see whether particular information is encoded in that brain region – for example whether the pattern of activity across voxels in that region differs depending on the particular visual stimulus the subject was shown.

In multivariate analysis, the data from each individual volume or measurement are taken, and used to construct a pattern vector that comprises the level of activity of each of the voxels in the area of interest. Many such vectors are collected, for each of the experimental conditions. These vectors are then used to train a computerised pattern classifier, by presenting it with multiple exemplar vectors for each condition. The classifier is then tested, by presenting it with a vector from an unspecified condition. If the classifier can reliably label such vectors correctly, this is evidence that the pattern of activity in the voxels in question contains information about the experimental condition.

If the activity level of a single voxel is viewed as a dimension, then the pattern vector containing activities of 2 voxels in can be seen as a specific point on a plane, and a pattern vector containing activities of n voxels as a point in n-dimensional space. The classifier attempts to find a boundary in this space which separates the points arising from one experimental condition from those points arising from an alternative condition. The algorithm representing this boundary might arise from a linear combination of voxel activations, or it might be non-linear. In the study described in Chapter 3, a linear classifier was used.

Chapter 3 The representation of emotions in the amygdala and fusiform gyrus: a study using multivariate analysis of imaging data

3.1 Introduction

The study described in this chapter investigates the processing of one of the most commonly investigated cues to emotion – the facial expression. As described in the introduction to this thesis, numerous brain regions have been identified as important in emotion recognition, but the precise role played by each of these regions is more difficult to ascertain. Knowledge in this area could be furthered by establishing what information about an emotional stimulus is encoded in a particular brain region. In this study, I used the technique of multivariate pattern recognition to investigate the nature of the information encoded in the activity of two brain regions: the amygdala, and fusiform face area.

As described in the introduction to this thesis, the amygdala shows a robust response to facial expressions of emotion. Early studies suggested that it was particularly sensitive to fearful faces (see introduction for further details and references). However, the findings from more recent studies indicate that the amygdala response may not be specific to particular emotions. Three studies have demonstrated an amygdala response to at least four emotions (Winston et al., 2003; Britton et al., 2006; Fitzgerald et al., 2006; see introduction for details). Two of these also found a response to neutral faces (Fitzgerald et al., 2006; Britton et al., 2006). Most notably, Fitzgerald et al. found that the amygdala does not discriminate between these different emotions in its level of activity.

There are two possible explanations for these findings. One is that the amygdala does not process information about the identity of individual emotions, and merely responds to faces of any emotion, as part of its role in the detection of salient visual stimuli (e.g. Sander et al., 2003). A second possibility is that the identity of emotions is reflected in the pattern of neural activity, but that this is at too small a spatial scale to be picked up by conventional fMRI analysis. To differentiate between these two

possibilities, it is necessary to investigate signals from the amygdala at a finer spatial scale. A study using intracranial electrodes implanted in the amygdalae of epilepsy patients found cells that discriminated, in their firing rate, between facial expressions of different emotions (Fried et al., 1997). Similarly, single-cell studies of the central nucleus of the monkey amygdala have revealed cells 'tuned' to expressions of a particular emotion (Kuraoka & Nakamura, 2006; Karaoka & Nakamura, 2007), some of which retain their preference for a particular emotion regardless of whether the cues are visual or vocal (Kuraoka & Nakamura, 2007).

Most functional imaging research to date has treated the amygdala as a discrete structural and functional unit. However, the mammalian amygdala is made up of several distinct nuclei (Amunts et al., 2005), which differ in their patterns of connectivity to other brain regions. This structural heterogeneity is likely to be reflected in a considerable degree of functional heterogeneity (Swanson & Petrovich, 1998). Some recent fMRI studies have attempted to localise BOLD responses to specific nuclei within the amygdala. A recent study in monkeys found that voxels sensitive to changes in facial expression were located in the basolateral (BL) amygdala, whilst those activated by contrasts involving gaze direction were located in the lateral extended amygdala (Hoffman, Gothard, Schmid and Logothetis, 2007). Similarly, Ball and colleagues investigated the response properties of three nuclei within the human amygdala using fMRI, and found distinct patterns of activity in these regions, with voxels within the BL region responding more strongly to auditory inputs than the superficial (SF) or centromedial (CM) regions. Also, BL voxels tended to show activations, whereas those in the other subregions showed deactivations (Ball et al., 2007).

The imaging findings discussed so far are from studies using conventional mass univariate methods of fMRI data analysis. Such methods characterise the activation level of each individual voxel in the amygdala region, independently of other voxels in the region, so patterns in activity across voxels are not explicitly considered. In contrast, the technique of multivariate pattern recognition, described in the Methods chapter of this thesis, makes explicit use of this information. The pattern of BOLD signal across all voxels in the area of interest is analysed. The BOLD patterns produced by different stimuli are used to train a pattern classifier, which is then tested

on its ability to discriminate between previously unseen patterns (Kamitani & Tong, 2005). Above-chance performance of the classifier indicates that information about the identity of the stimuli is contained in the pattern of activity across these voxels.

Multivariate analysis can potentially provide a bridge between single-cell studies and conventional MRI analysis (Haynes & Rees, 2006). One example of this is in the study of the representation of orientation in the early visual cortex (area V1). Single-cell studies have shown that this region contains neurones tuned to particular orientations (Wang, Tanaka & Tanifuji, 1996). However, clusters of neurones containing similar orientations are separated from one another by distances of only approximately 500μm: much smaller than the typical 1.5-3mm resolution of fMRI. Nevertheless, because of chance variation in the distribution of these clusters, some voxels will demonstrate a tuning preference for one orientation over another. Therefore different orientations will elicit different patterns of activity across voxels (Kamitani & Tong, 2005; Haynes & Rees, 2005), even if each individual voxel only exhibits a weak preference for a particular orientation that would not reach significance in a conventional univariate analysis.

Like single cell studies, multivariate analysis is performed on a per-subject basis. This is because similarities between brain structure and function across individuals exist at the scale of a few millimetres, but the voxel-to-voxel activation patterns in response to a stimulus will differ between subjects. Thus the classifier is trained and tested on the data from one individual at a time. The accuracy of the classifier can then be compared across subjects and a mean accuracy computed as well as a measure of variability.

In the study described in this chapter, I used multivariate analysis to investigate whether the identity of individual emotions, as present in facial expressions, is represented in the amygdala. Given that single-cell studies have demonstrated 'tuning' for emotion in amygdala neurones (Fried et al., 1997; Kuraoka & Nakamura, 2006; Kuraoka & Nakamura, 2007), it is possible that uneven distribution of clusters of these neurones could lead to some voxels being tuned to particular emotions. I therefore predicted that multivariate analysis of fMRI data from the amygdala would

reveal distinct patterns of activity elicited across these voxels by different emotions, as detectable by a pattern classifier.

I also investigated the representation of facial expressions of emotion in the fusiform face area (FFA). This is a subregion of the fusiform gyrus that appears so be specialised for the processing of faces (Kanwisher, McDermott & Chun, 1997). Its role in the processing of the invariant aspects of a face such as identity is well documented, and there is evidence from single-unit studies that facial identity might be represented in the fine-grained pattern of activity in this region. Tsao et al. (2006) studied the responses of single cells in the macaque 'middle face patch', a region thought to be homologous to the human FFA (Tsao et al., 2003). They found evidence for a distributed representation of facial identity. Although any one unit responded to a wide range of faces, when the responses from 94 cells were analysed together, the information could be used to predict correctly the identity of a face on 74% of occasions. With regard to how facial identity is encoded in the human FFA, however, it has been suggested that this is achieved through more narrow tuning of neural populations, in manner similar to 'labelled-line' coding (Gilaie-Dotan & Malach, 2007). This was inferred indirectly, from an fMRI study using an adaptation paradigm - the human FFA has not yet been investigated at the level of individual neurones. Invasive studies of this region have so far been limited to the collection of intracranial population recordings (e.g. Puce, Allison & McCarthy, 1999).

In addition to its role in processing facial identity, some evidence suggests that the FFA might be involved in emotion recognition. For example, activity in the fusiform gyrus is modulated by the emotional expression which a face displays. Vuilleumier et al. (2001) found that activity in the fusiform gyrus was greater in response to fearful than neutral faces. Similarly, Winston et al. (2003) found that the fusiform gyrus responded more to high than low intensities of emotional expression for four emotions (disgust, fear, happiness and sadness). I aimed to investigate, using the multivariate techniques described above, whether this modulation of activity reflects a representation of emotional identity within the FFA.

3.2 Methods

3.2.1 Participants

9 healthy adults (6 females; mean age 26.9±4.75) were recruited. All had normal or corrected-to-normal vision, and were screened to rule out medication use, and a history of neurological or psychiatric disorders. All participants gave informed consent, and the study was approved by the local ethics committee.

3.2.2 Stimuli and procedure

Stimuli were greyscale photographs of facial expressions, taken from a standard set of pictures of facial affect (Ekman & Friesen, 1976). Participants saw photographs of faces displaying four different emotions: angry, fearful, disgusted and neutral. For each emotion, there were photographs of ten different individuals: 5 males, and 5 females. A mask was applied to each photograph to cover the hair, so only the face was visible. Photographs were presented centrally, and subtended 3 by 4 degrees of visual angle. A central fixation cross was superimposed on each photograph, and participants were instructed to look at this point throughout.

Photographs were displayed in blocks, each containing 40 faces of a single emotion. During each block, faces were displayed for 700ms each, with no pause between faces. Faces appeared in a pseudorandom order, in which no two consecutive faces were identical. Whilst viewing the photographs, participants were required to judge whether each face was male or female, and press one of two buttons accordingly. Participants practised this task prior to scanning.

Each block (of duration 28 seconds) was followed by a rest period of 14 seconds, in which a blank screen was displayed with a central fixation cross. 15 blocks of each emotion were shown, making a total of 60 blocks, which occurred over 4 sessions of 10.5 minutes each. The order of the blocks was counterbalanced across participants.

After presentation of the main experimental stimuli, participants viewed a set of 'localiser' stimuli, designed to elicit activity in the fusiform face area, as this varies in its precise location amongst individuals. These comprised four types of stimulus: faces, scrambled faces, houses and scrambled houses. Participants viewed five blocks

of stimuli. Each block lasted 72 seconds, and comprised 16 presentations of each of the four stimulus types. Again, photographs were presented centrally, and subtended 3 by 4 degrees of visual angle. Participants were instructed to look at the centre of the screen throughout.

3.2.3 Data acquisition

I acquired gradient echo T2*-weighted echo-planar images (EPIs) with blood oxygen level dependent (BOLD) contrast on a Siemens Allegra 3.0 Tesla MRI scanner, equipped with a transmit-receive quadrature head coil (repetition time [TR] = 102ms, echo time [TE] = 30ms, flip angle = 90°, slice thickness = 1.5mm, interslice gap = 0mm, slices per volume = 35, in-plane resolution = 1.5 x 1.5mm, voxel size = 1.5 x 1.5 x 1.5mm). In each session of 10.5 minutes, 188 volumes were collected; this included six 'dummy' volumes at the start of each session. During the presentation of the 'localiser' stimuli, 120 volumes were collected, again including six dummy volumes. Slices were positioned for each subject to ensure coverage of the amygdala and the fusiform gyrus. A T1-weighted structural image was also acquired for each participant.

During scanning, eye-position data were collected using an ASL 5000 eye-tracker with long range optics, to ensure that participants maintained fixation during presentation of the stimuli.

3.2.4 Image preprocessing

Preprocessing of images was conducted using SPM5 (http://www.fil.ion.ucl.ac.uk/spm/software/spm5) implemented in MATLAB 7.0.4 (Mathworks Inc, Sherborn, MA). Images were first realigned and unwarped, using fieldmaps collected during scanning. Second, the structural image for each participant was coregistered to the space of his or her functional scans. The structural image was then segmented, and normalised, and these normalisation parameters were used to normalise the functional images for this participant. The functional images were smoothed with a 6mm full width half maximum Gaussian kernel, though in the subsequent analysis of the data, the multivariate analysis was performed on the unsmoothed data.

3.2.5 Data analysis

3.2.5.1 Analysis of localiser data

First, fMRI data acquired during presentation of the localiser stimuli were analysed individually for each participant, to ascertain the likely location of the fusiform face area. Analysis was conducted using SPM5, and entailed the creation of statistical parametric maps, representing a statistical assessment of hypothesised condition-specific effects. First, subject-specific low-frequency drifts in the signal were removed using a high-pass temporal filter with a cutoff period of 128 seconds. Global normalisation was achieved using session-specific grand mean scaling. Then, condition-specific effects were estimated with the General Linear Model. The four different block types (faces, scrambled faces, houses, and scrambled houses) were modelled by convolving the onset times and durations of these blocks with a canonical haemodynamic response function. Parameters for each regressor were estimated, and the contrast of interest (faces versus scrambled faces) was used to compute a t-statistic for each voxel in the brain. This was transformed into a map of Z-values. I selected the most active cluster in this map which had its voxel of peak activity within the fusiform gyrus. The threshold p-value was adjusted individually for each subject to ensure a cluster of at least 100 voxels which was limited to the fusiform gyrus. A mask was generated that corresponded to all suprathreshold voxels within this most active cluster in the fusiform gyrus, on either side of the brain. This mask was then used in the multivariate analysis of the data (see section 3.2.5.3). The coordinates of the peak voxels for the left and right clusters are given in Table 1.

Subject	Left	Right
1	-41 -63 -15	46 -54 -20
2	-41 -59 -15	36 -53 -20
3	-38 -64 -15	42 -53 -21
4	-42 -72 -16	43 -65 -19
5	-39 -69 -15	44 -61 -18
6	-36 -73 -19	31 -66 -15
7	-35 -59 -20	35 -73 -19
8	-33 -48 -18	38 -66 -16
9	-41 -71 -19	47 -67 -17

Table 1. Coordinates of the voxels of peak activity in the clusters used to create the FFA mask for each subject

3.2.5.2 Univariate analysis of functional data

Functional data from the main part of the experiment were first analysed in a univariate (conventional) manner, again using SPM5. As with the data from the localiser sequence, global changes in activity were removed using session-specific grand-mean scaling. However, due to the timing of the blocks in this part of the experiment, a high-pass temporal filter was not applied, to avoid inadvertently filtering out variations in the BOLD signal that were due to experimental manipulations.

Condition-specific effects were estimated with the General Linear Model. Random effects statistical analysis was undertaken in two stages. In the first stage, the five different event types (angry, fearful, disgusted and neutral faces, and fixation periods) were modelled by convolving the onset times and durations of these events with a canonical haemodynamic response function (HRF). Movement parameters were included as nuisance regressors. To allow for habituation effects over the course of a block, 'time into block' was included as a parametric modulator. Parameters for each regressor were estimated using a subject-specific model. Linear contrasts were used to obtain subject-specific estimates for the effects of interest (for analysis of the FFA: all faces versus fixation crosses; for analysis of the amygdala: emotional versus neutral faces, and fearful versus neutral faces). These estimates were entered into the second stage of analysis treating subjects as a random effect, using one-sample *t* tests across subjects. Statistical contrasts were used to compute a t-statistic for each voxel within the brain, which was transformed into a map of Z-values.

For the amygdala, a region-of-interest (ROI) analysis was then conducted. The ROI mask encompassed all subnuclei of both amygdalae, and was created using the SPM Anatomy toolbox (Eickhoff et al., 2005) which, for the amygdala, is based on cytoarchitectonic probabilistic maps (Amunts et al., 2005). A small-volume correction was performed on the Z-values, based on the volume of the ROI, and the resulting Z-values were thresholded at $p<0.05$ (False Detection Rate corrected).

For the FFA, as the ROI mask was created individually for each subject, it could not be used in the random-effects analysis. Instead I report p-values FDR corrected for the whole brain, again thresholded at $p<0.05$.

3.2.5.3 Multivariate analysis of functional data

Multivariate analysis was conducted outside SPM, with the raw fMRI signal from every voxel and every volume of fMRI data collected, for each subject individually. For both the amygdala and the FFA, the value of the BOLD signal at each individual voxel within the ROI was extracted from the fMRI dataset for each volume. Time-series corresponding to the four different block types (angry, fearful, disgusted and neutral) were extracted. These comprised a total of 135 measurements for each voxel, for each of the four block types. From these time series, the 100 voxels were selected which showed the greatest summed response (including both activations and deactivations) across all four categories.

The time series for these voxels were divided into fifteen sets of data, each containing 9 measurements (corresponding to a presentation of a single block of stimuli) for each block type. Data from each measurement comprised a pattern vector, with one value, representing the raw BOLD signal, for each voxel in the ROI.

These vectors were used to train a pattern classifier, implemented in MatLab 7.0.4. Classification was performed with linear discriminant analysis (Duda, Hart & Stork, 2001). A standard leave-one-out cross-validation scheme was employed, in which the classifier was trained on 14 of the 15 sets of vectors, with the remaining dataset being used to test the performance of the classifier. Data from the test set were added to the classifier one voxel at a time, up to the full 100 voxels. This process was repeated fifteen times, each time with a different block used as the test dataset. The mean accuracy of the classifier at the stage of addition of each voxel was computed.

These accuracy values were then averaged across subjects to give the curves shown in Figure 2. The mean performance of the classifier across subjects was compared to a level of 25% which would indicate performance at chance.

3.3 Results

3.3.1 Behavioural results

All participants scored above chance on the gender discrimination task for all experimental runs (Table 2), indicating that participants attended to the stimuli. Inspection of gaze trails recorded by the eye-tracking software indicated that all participants maintained fixation of the experimental stimuli.

Subject	Run 1	Run 2	Run 3	Run 4
1	84.83	87.93	86.33	85.17
2	70.50	69.67	71.67	72.33
3	70.17	75.00	81.67	81.33
4	59.67	60.33	56.17	60.00
5	78.33	73.50	68.67	71.17
6	86.83	89.50	92.83	90.83
7	83.00	83.00	85.33	88.17
8	56.00	64.83	67.00	62.83
9	80.17	76.17	87.33	84.00

Table 2. Percentage of correct responses in the gender discrimination task for all subjects

3.3.2 Results from univariate analysis

The random-effects analysis revealed significant activation in the amygdala bilaterally for emotional versus neutral faces (left: Z=3.05, p=0.045, small volume corrected, cluster size = 571 voxels; right: Z=3.66, p=0.004, small volume corrected, cluster size = 1401 voxels) and in the right amygdala for fearful versus neutral faces (Z = 5.05, p = 0.002, small volume corrected, cluster size = 160 voxels). There was no activation in response to the contrast of all faces versus fixation.

The contrast of all faces versus fixation did however activate the fusiform gyrus bilaterally, at coordinates similar to the presumed location of the FFA in all subjects, based on data from the localiser stimuli (table 1). Peak activation in the left fusiform gyrus was at -33 -47 -20 (Z = 3.73, p = 0.025, cluster size = 574 voxels), and in the right fusiform gyrus was at 33 -48 -17 (Z = 4.74, p = 0.012, cluster size = 4149 voxels). Other regions in which activation survived FDR correction for the whole brain were the left inferior occipital gyrus and the right putamen. For the contrasts of emotional versus neutral faces, and fearful versus neutral faces, no activations survived whole-brain FDR correction.

3.3.3 Results from multivariate analysis

For both the amygdala and the FFA, the classifier did not perform significantly above chance when averaged across participants (figure 2). Given the significant activation of the amygdala in response to fearful versus neutral faces, found in the univariate analysis, I also tested the performance of the classifier on a 2-way discrimination of fearful and neutral faces, using the pattern vectors from the amygdala voxels. Again, the classifier did not perform significantly above chance (Figure 3).

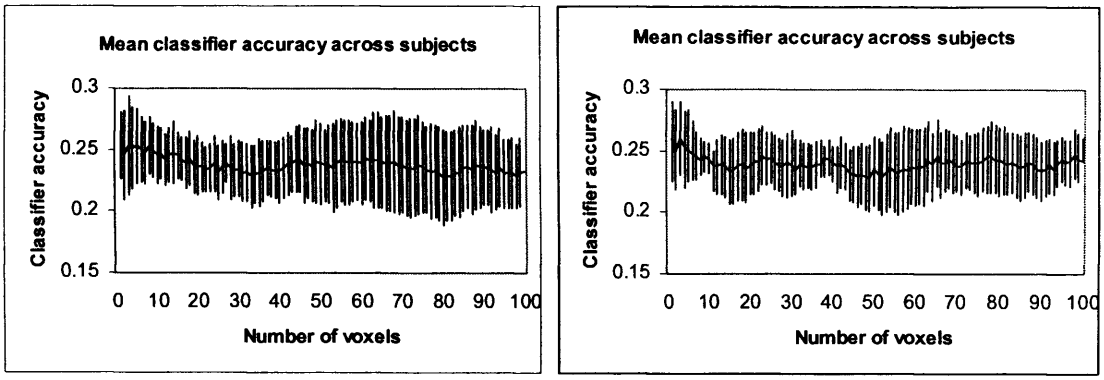

Figure 2. Performance of the classifier on a four-way discrimination between angry, fearful, disgusted and neutral faces, using pattern vectors extracted from the amygdala (left) and FFA (right). This figure shows mean performance across all subjects; error bars show standard deviation. The classifier was unable to classify pattern vectors in the test data set at a level of accuracy above the 0.25 that would be expected by chance.

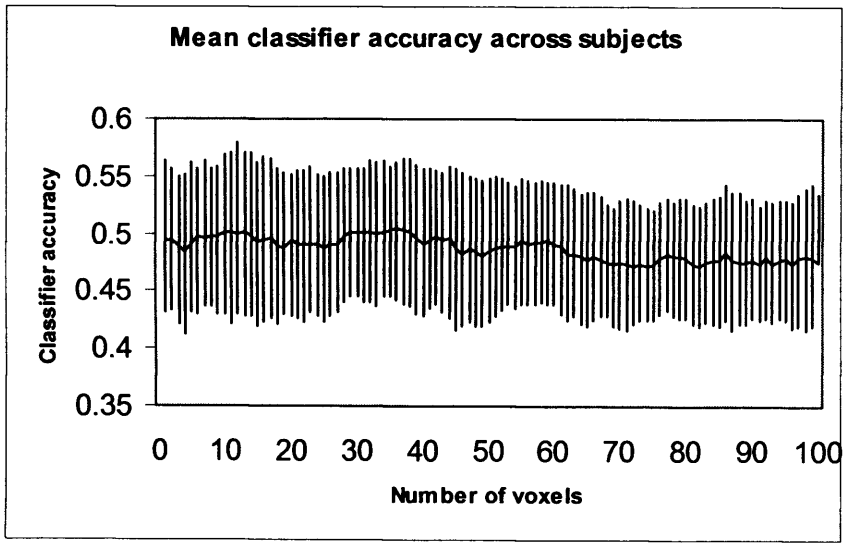

Figure 3. Performance of the classifier on a two-way discrimination between fearful and neutral faces, using pattern vectors extracted from the amygdala. This figure shows mean performance across all subjects; error bars show standard deviation. The classifier was unable to classify pattern vectors in the test data set at a level of accuracy above the 0.5 that would be expected by chance

3.4 Discussion

The aim of the study described in this chapter was to clarify the role of the amygdala and the FFA in emotion recognition, by investigating whether either of these areas held a representation of individual emotions in their fine-grained pattern of activity across voxels. Typical response patterns for these regions were found in the initial univariate analysis: namely, a response to faces compared to a baseline fixation condition in the FFA, and a response to emotional compared to neutral faces, and to fearful compared to neutral faces in the amygdala.

It should be noted that this third finding is in line with early findings of a main effect of fearful faces in the amygdala (Breiter et al., 1996; Morris et al., 1996; Phillips et al., 1997; Phillips et al., 1998), but in contrast to Fitzgerald and colleagues' recent finding that the amygdala does not discriminate between fear and other emotions in its activity level (Fitzgerald et al., 2006). Taken together, therefore, the univariate data on the amygdala are equivocal on this issue. It is partly for this reason that the multivariate analysis detailed in this study was undertaken.

The failure to find above-chance performance of the classifier with data from these regions makes it impossible to draw firm conclusions about the nature of representations in these areas. Had I had found evidence of a representation of individual emotions in the amgydala, it have been incongruent with the idea that the amygdala is simply a general-purpose salience detector, and would have been in line with the evidence from single-cell studies (e.g. Fried et al., 1997). Similarly, evidence of a representation in the FFA would have indicated that this area has a role in the discrimination of facial emotions, as well as facial identity.

However, a failure to find above-chance performance of the classifier does not necessarily mean that facial expression is not represented at all in these regions. It is possible that a non-linear (or other type of) classifier would have performed at levels above chance, given these data. However, non-linear classifiers operate by combining data across voxels in a non-linear fashion i.e. can operate on representations that are not physically present in the brain. Interpretation of a non-linear classification finding in terms of brain activity is therefore difficult. Alternately, a representation might be

present but at too small a spatial scale to be detectable by current fMRI techniques, in which case a more invasive technique would be necessary to identify such a representation.

In the case of fearful versus neutral faces, the failure to find above-chance performance is surprising given the significant univariate result. However, this could be due to the fact that the univariate analysis techniques enabled the removal of movement noise from the data, which increased the power to some extent. Also, the classifier was not trained on data from the whole amygdala, but just a small subset of voxels. A different subset of voxels might have yielded a significant result. Improved methods of selecting the appropriate voxels for input to the classifier may allow refinement of future multivariate studies.

Taken together, the univariate and multivariate results can not demonstrate conclusively that the identity of individual emotions is coded in either the amygdala or the FFA. It is possible that this information is indeed not coded in either of these areas, but elsewhere in the brain instead. One candidate region for holding this representation is the superior temporal sulcus (STS), which is also activated by emotional stimuli (Phillips et al., 1998). The implications of such a representation are discussed further in the general discussion of this thesis.

A major limitation to the methodology of this study was the need to normalise the data prior to multivariate analysis. This is problematic because the normalisation step involves a certain degree of smoothing, which removes fine-grained differences in the BOLD signal from voxel to voxel. This could be another reason why above-chance classification performance was not possible from the data collected here. If the study had been on the FFA alone, it would not have been necessary to normalise the data. This is because the FFA is identifiable in an individual brain, using a set of localiser stimuli. However, a reliable localiser for the amygdala does not exist. Also, the amygdala is not easy to define on a person's T1 structural scan, as it is difficult to distinguish it from the hippocampus (Amunts et al., 2005). For this reason, I used a probabilistic map, which was in normalised space, therefore the data needed to be normalised for each participant.

An interesting extension to this study would be to investigate in the same study the representation of both facial expression and facial identity, to look for evidence that the different attributes of a face are processed in distinct streams. The stimuli for this study did include faces of different individuals. However, data from this study can not be used to answer this particular experimental question, as the faces were not blocked according to identity, so there would be insufficient power in this case. Blocking the faces according to identity would have interfered with the gender judgement task, which was necessary to ensure that participants paid attention to all of the faces.

It might also be profitable in future studies to apply the multivariate analysis techniques employed here to the analysis of other brain regions implicated in emotion recognition, such as the STS, IFG, or orbitofrontal cortex. These regions were not investigated in this study. Firstly, a limited number of slices were used, so fMRI data was not collected from these regions during scanning. Secondly, the amygdala and FFA were selected because they are easily identified and delimited – the FFA by a well-established set of localiser stimuli, and the amygdala by a set of probabilistic cytoarchitectonic maps. At present, these other regions can not be so easily delimited, but with the cytoarchitectonic mapping of further brain regions, and a better understanding of the stimulus properties which reliably activate this regions, this situation is likely to improve in the near future.

In the studies described in the subsequent chapters of this thesis I investigate the brain basis of emotion recognition from a much less-studied cue: that of social movement. The final chapter describes another study looking at face processing, but with a task which has been little studied: the discrimination of posed and genuine smiles.

Chapter 4 Emotion recognition from social movement

4.1 Introduction

Facial expressions, as investigated in chapter 3 of this thesis, evolved specifically as a means of communicating one's emotional state to others (Darwin, 1872). However, other aspects of an individual's demeanour may vary as a function of their emotional state. The study described in this chapter investigated whether these other changes can be used as cues to deduce the emotional state of another individual. Specifically, I focused on the cues provided by an individual's movement.

Evidence that the movement patterns of an individual can provide information about his or her emotional state comes from studies where subjects view point-light displays. These are created by filming a moving person in a dark room, with light sources attached to the joints of the body (Johansson, 1973). Even with this limited amount of visual information, subjects can recognise the particular emotion felt by the person represented by the point-lights (Heberlein et al., 2004).

The movement patterns depicted in such point light displays can be described as biological motion. The trajectories followed by the points are characteristic of the movement produced by a biological entity (human or animal) – specifically, with a pattern of acceleration and deceleration that creates 'minimum jerk', or maximum smoothness (Hogan, 1984). The current study does not focus on the biological nature of motion, but is more focussed on the purpose of the motion – analysing motion as behaviour. Although facial expressions are seen as characteristic of the human emotions, they are largely divorced from the functions of the emotions themselves. From an evolutionary perspective, emotions exist to drive behaviour (Dolan, 2002). Each emotion therefore has a particular behaviour or class of behaviours associated with it. Indeed, one popular way of classifying emotions is by the type of behaviours which they promote, i.e. approach versus withdrawal (Davidson & Irwin, 1999).

This study tested the hypothesis that simple representations of the behaviours associated with basic emotions could reliably evoke the impressions of these

emotions, in the absence of any other cue. To test this, a set of stimuli were developed that contained only movement cues. This was achieved using abstract animations, featuring geometric shapes (a triangle and a circle), apparently engaged in simple interactions.

Similar abstract animations have been used for many decades to test mental state attribution (Heider & Simmel, 1944). Viewers tend to attribute mental states to geometrical shapes if they move in a 'social' way, i.e. if one shape moves in a self-propelled manner and is seen to influence the movements of another in a manner more complex than simple physical causality (Bloom & Veres, 1999; Heider & Simmel, 1944).

In the current study, animations were developed depicting four basic emotions: anger, happiness, sadness and fear, and incorporated into a task that measured an individual's ability to attribute the intended emotion to an animation. After a test of reliability, this task was administered to a large epidemiological sample. Within this sample the effect of age, sex, IQ and social communication ability on task performance was assessed.

4.2 Development of an animated emotion-recognition task

4.2.1 Methods

4.2.1.1 Development of animated stimuli

Eight silent animations were created, each featuring a black outline triangle and a black outline circle moving on a white background (Figure 4). In these animations, the triangle moved in a self-propelled, non-linear manner, designed to evoke the impression that it was '*living*' or animate (Scholl & Tremoulet, 2000, Blakemore et al. 2003). Each animation was designed to evoke the attribution of a particular emotion: angry, happy, sad or scared, with two examples of each. The impression of emotion was created through an apparent interaction between the triangle and the circle. For example, in a 'scared' animation, the triangle appeared to 'run away' from the circle, whereas in a 'happy' animation it approached the circle in an affectionate manner. In an 'angry' animation, the triangle jabbed repeatedly at the circle, and in a 'sad'

animation it 'pushed away' the circle when it was approached. The animations were of similar duration for all emotions (angry = 5.5s, happy = 5.6s, sad = 5.5s, scared = 5s). The trajectory of movement of the circle was identical in all eight animations. (Animations can be found at http://www.icn.ucl.ac.uk/sblakemore/). Animations were designed using Flash MX 2004.

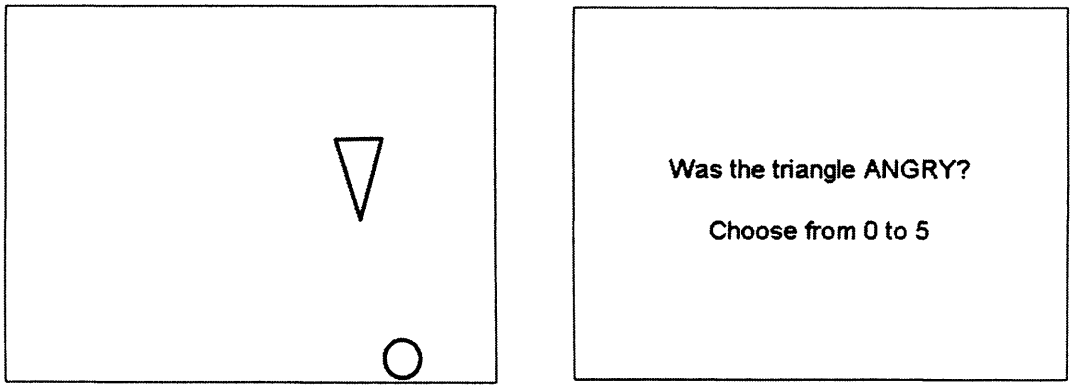

Figure 4. Frame from one of the eight animations, showing the circle and triangle, and the following question. Animations were designed to evoke the attribution of a particular emotion (angry, happy, sad or scared), and were followed by a question in which the participant selected their response from a numerical rating scale.

4.2.1.2 Task design

The animations were incorporated into a task that was designed to assess the observer's ability to identify the intended emotion in each of the animations.

Responses were collected in the form of numerical ratings in response to a specific question, rather than forced-choice responses. This was to maximise the information available from each trial, and to reduce ceiling effects. Questions were presented after each animation, and were of the format: 'was the triangle ANGRY?' Each animation was shown twice, with two different questions. One of these referred to the actual emotion intended to be perceived in the animation. The other referred to an alternative emotion that was not intended to be perceived. For angry animations the alternative emotions were happy and scared; for happy animations the alternatives were angry and sad; for sad animations they were scared and angry, and for scared animations they were happy and sad. Participants answered the emotion question using a rating scale from 0 ("not at all...") to 5 (extremely...").

4.2.1.3 Generation of emotion-recognition scores

For each animation, participants gave a rating for the actual emotion present, and an alternative emotion. Accurate recognition of the emotion would be indicated by a high rating for that emotion, and a low rating for any of the three possible alternative emotions. These ratings were therefore used to calculate a score by subtracting the alternative emotion rating from the actual emotion rating. This produced a score ranging from –5 to +5, with a higher score indicating a greater accuracy in correctly identifying the actual emotion. This meant that a high score could not be achieved by indiscriminately giving high ratings in response to all questions. Scores were averaged across the two presentations of each emotion.

4.2.1.4 Assessment of reliability of emotion-recognition test

As this test is a novel measure, its reliability was assessed using a test-retest paradigm. 20 normal adults (10 males; mean age = 26.2 ±4.0 years) were tested twice, with an interval of between 5 and 14 days.

Animations were presented to the subject using Matlab v6.5, and Cogent Graphics, on a Dell Latitude 100L laptop computer with a 15" LCD display screen. The rating scale was explained to each participant before the experiment, and participants completed four practice trials. Before the main part of the task, participants completed a control task, with four animations – a subset of the animations used in the main task. Participants were required to indicate, using the same 0-5 rating scale, the vertical position of the triangle on the screen at the end of animations, with 5 representing the top of the screen, and 0 representing the bottom. This task was designed to ensure that the participant was able to perceive and attend to the animations, read the questions, and use the rating scale. Participants who did not complete this task correctly were excluded from the study.

As described in section 4.2.1.3 this test yields, for each participant, a score indicating their ability to recognise each of the four emotions. For the evaluation of test reliability, these scores were then averaged across all four emotions to generate a single score for each of the two testing occasions. For each participant these scores were compared for time 1 and time 2 as a measure of reliability, and used to calculate

an Intraclass Correlation Coefficient (Shrout & Fleiss, 1979), as well as a Technical Error of Measurement (Mueller & Martorell, 1988).

4.2.2 Results

All participants completed the control task correctly and so no participants were excluded. As described in section 4.2.1, test-retest data comprised two scores for each participant, obtained at two timepoints, separated by between 5 and 14 days. First, the scores for each participant from time 1 and time 2 were subtracted to give a difference score. The mean difference score was 0.03 ± 0.96, with only four of the 20 participants obtaining a difference score of greater than one point. A Bland-Altmann plot (Bland & Altmann, 1986) of these differences (Figure 5) shows that the difference score does not depend on the subject's overall score, i.e. the reliability of the test is not affected by the level of performance.

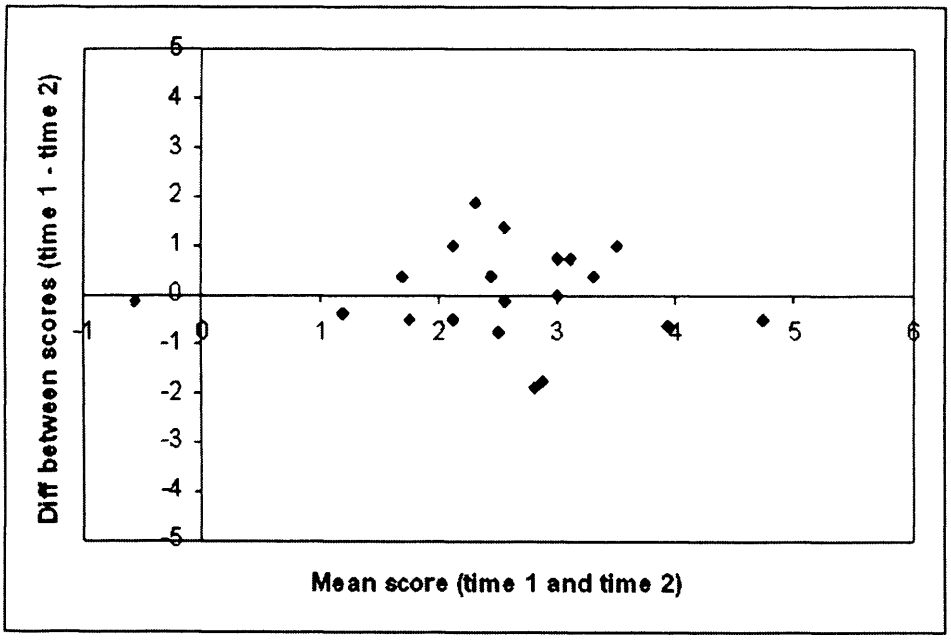

Figure 5. Bland-Altmann plot of participants' scores at time 1 and time 2 in the test-retest paradigm. The x-axis shows the mean score of each participant (maximum score = 5; a score of zero indicates performance at chance). The y-axis shows the difference between that subject's scores for time 1 and time 2.

Scores from the two testing sessions gave an intraclass correlation coefficient of 0.69, which falls within the 'good' range (Cicchetti, 1994), and a technical error of measurement of 0.66, indicating reasonable agreement between testing sessions.

4.3 Emotion recognition in a large epidemiological sample

4.3.1 Methods

The task developed in section 4.2 was administered to a large sample of adolescents, as part of the Avon Longitudinal Study of Parents and Children at Bristol University. The original sample for this study was recruited by approaching women in the Avon area who were expecting a baby between 1st April 1991 and 31st December 1992.

The core ALSPAC sample consists of 14,541 pregnancies. An additional 542 eligible pregnancies not in the core sample, who were invited to participate at age 7 and for whom research data were available in November 2004, were included in this study. These 15,083 pregnancies resulted in 15,224 known fetuses of which 14,610 were live births. For reasons of confidentiality, data on the 13 triplet and quadruplet children were not available for analysis.

This task was administered when the children in the study were between the ages of 12 years, 6 months and 14 years, 7 months, as part of a half-day of tests completed at a designated testing centre. Testing was conducted by the ALSPAC team. At the time of completion of this thesis, testing was still in progress, and 2230 children had been tested.

As the aim of this experiment was to look at the distribution of responses across a large sample of the population, all children who completed the task were included in the analysis. There were no exclusion criteria. Of the 2230 children tested, 2219 completed the task. Of these, 1108 were males. The mean age at participation was 13 years and 10 months. IQ data were available for 2190 of the children. The mean verbal IQ was 109±17, and mean performance IQ was 103±17.

A further aim was to investigate the effect on task performance of variables such as age, IQ, and social and communication ability. The latter of these variables was investigated using the Social and Communication Disorders Checklist (SCDC; Skuse, Mandy & Scourfield, 2005), a 12-item parental questionnaire which assessed skills in the child such as an awareness of others' feelings, an ability to read body language, and an understanding of socially acceptable behaviour, as well as assessing the impact of the child's behaviour on family life. This questionnaire generates a score out of 24 for each child, with a higher score indicating a greater degree of social or communicative impairment. SCDC scores were available for 1799 of the 2219 children who completed the emotion recognition task.

4.3.2 Results

First, I looked at the distribution of scores on this task across the population. Figure 6 shows these distributions, separately for the individual emotions and averaged across emotions. The histograms show a skew due to a ceiling effect for the individual emotions, particularly angry and happy. However, the histogram for the averaged score, representing overall emotion recognition ability as measured by this task, does not show this ceiling effect.

To allow for differences in the way that the rating scales might be used amongst participants, I also conducted a simplified analysis of the data in this sample. Here, instead of calculating a difference between two ratings, I scored the response to an animation as correct if the rating for the intended emotion was higher than the rating for the alternative emotion. This generated a simplified emotion recognition score for each participant with a maximum of 8 and a minimum of zero. Figure 7 shows the distribution of this score across the population. Although there is some negative skew in this distribution, the modal score was slightly lower than the maximum possible score, indicating that a severe ceiling effect was not present even in this simplified measure.

The second aim of this study was to see whether the animations reliably elicited the perception of the intended emotions. The scoring system subtracted a participant's rating for the inappropriate emotion from that for the appropriate emotion. An

inability to discriminate the appropriate from the inappropriate emotion would therefore on average lead to score of zero.

For each of the emotions, I therefore tested whether the average score was significantly greater than zero, which would indicate an ability to recognise the intended emotion in the animations. Although the data differed from a normal distribution (for the average score, Shapiro-Wilk statistic = 0.995, $p<0.001$), and were slightly skewed (for average score, $z_{skewness} = -3.154$), the sample size was large enough to apply parametric statistical tests.

A one-sample t-test was applied for each of the four emotions, and for the average score. The results revealed a significant difference from zero for each of the four emotions (angry: $t_{(2218)} = 85.15$, $p < 0.001$; happy: $t_{(2218)} = 61.99$, $p < 0.001$; sad: $t_{(2218)} = 59.42$, $p < 0.001$; scared: $t_{(2218)} = 66.02$, $p < 0.001$, all 1-tailed), and for the average score ($t_{(2218)} = 106.6$, $p < 0.001$, 1-tailed).

Finally, I assessed the relationship between an individual's score on this test and his or her age, IQ, and SCDC score. A Pearson's test revealed a slight but statistically significant correlation between task performance and verbal IQ ($r^2 = 0.02$, $p < 0.001$), and between task performance and performance IQ ($r^2 = 0.03$, $p < 0.001$). There was a slight but statistically significant negative correlation between task performance and age ($r^2 = 0.006$, $p < 0.001$). Finally, there was a slight but statistically significant relationship between scores on the SCDC and the emotion recognition task, with children with a higher SCDC score (i.e. more severe social and communicative impairment) scoring less highly on the emotion recognition task ($r^2 = 0.005$, $p = 0.004$).

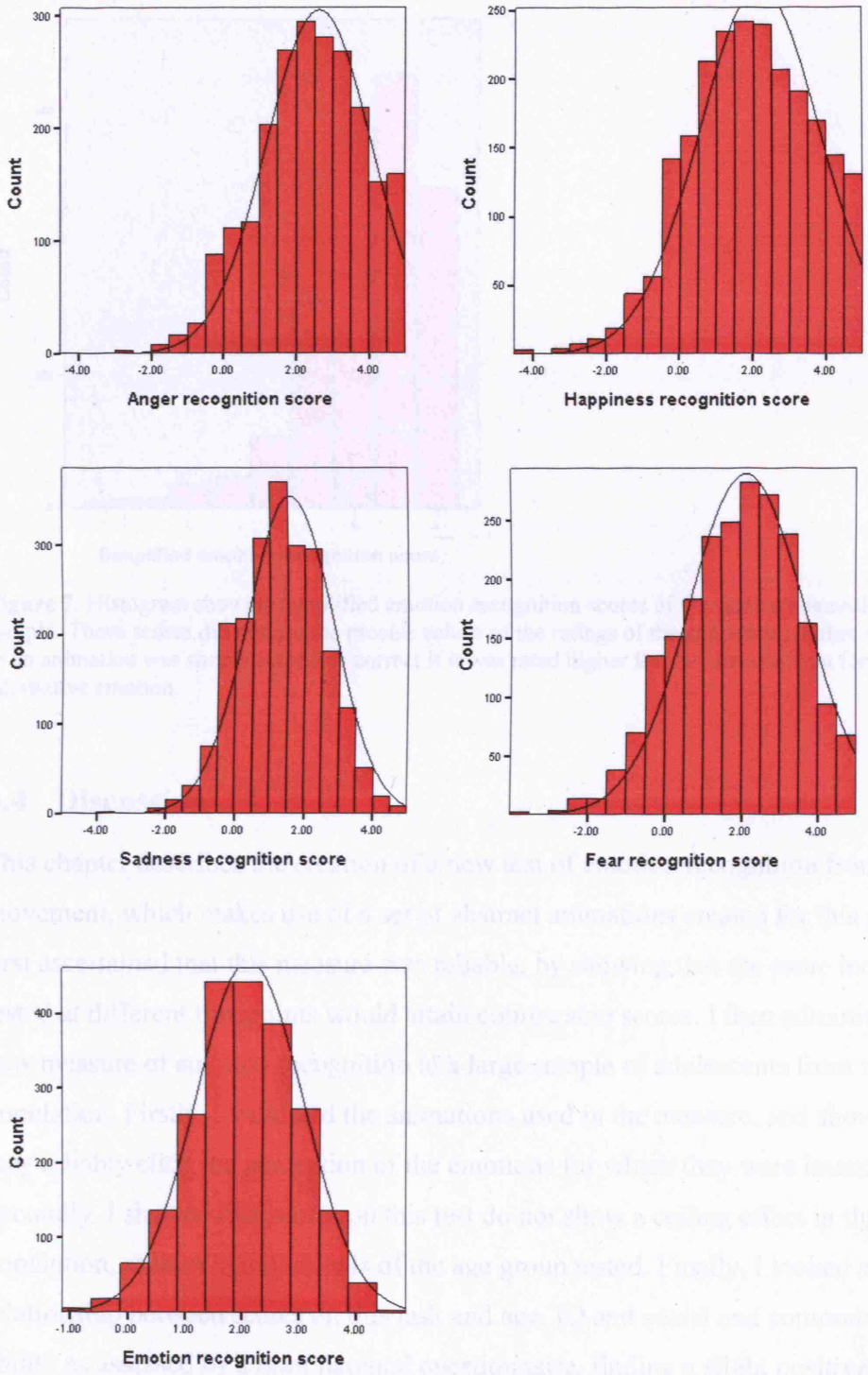

Figure 6. Histograms showing emotion recognition scores of an epidemiological sample of 2219 teenagers, for the four individual emotions (top) and overall scores (bottom).

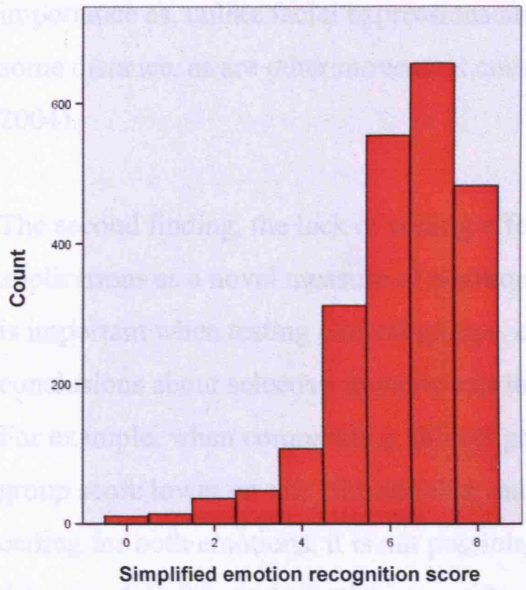

Figure 7. Histogram showing simplified emotion recognition scores of the same epidemiological sample. These scores did not use the precise values of the ratings of the animations, rather the response to an animation was simply scored as correct if it was rated higher for the intended than for the alternative emotion.

4.4 Discussion

This chapter describes the creation of a new test of emotion recognition from social movement, which makes use of a set of abstract animations created for this purpose. I first ascertained that this measure was reliable, by showing that the same individual tested at different timepoints would attain comparable scores. I then administered this new measure of emotion recognition to a large sample of adolescents from the general population. Firstly, I validated the animations used in the measure, and showed that they reliably elicit the perception of the emotions for which they were intended. Secondly, I showed that scores on this test do not show a ceiling effect in the general population, at least in individuals of the age group tested. Finally, I looked at the relationship between scores on this task and age, IQ and social and communication ability as assessed by a brief parental questionnaire, finding a slight positive correlation with IQ and social commucation ability, and a slight negative correlation with age.

The first of these findings from the adolescent sample confirms that an individual's movement patterns in relation to others, even in the absence of any other cues, are

sufficient to elicit an impression of emotion. Such cues are potentially of ecological importance as, unlike facial expressions and vocal cues, they are detectable from some distance, as are other movement cues such as gait patterns (Heberlein et al., 2004).

The second finding, the lack of ceiling effect, suggests that this task might have applications as a novel measure of emotion recognition. An absence of ceiling effect is important when testing clinical groups, especially when wishing to draw conclusions about selective impairments to the recognition of individual emotions. For example, when comparing a clinical group with a control group, if the clinical group score lower on one emotion than another, and the control group perform at ceiling for both emotions, it is not possible to conclude that the clinical group has a selective deficit in one emotion, as we do not know if tests for the two emotions were of equal difficulty.

Ceiling effects are a particular problem in designing tasks of emotion recognition, as in the normal population emotion recognition is a well-practised, seemingly effortless skill. If a test is too easy, it will not reveal deficits that might exist in a clinical population. For example, Baron-Cohen et al found that adolescents with Asperger syndrome showed no deficit in the recognition of basic facial expressions of emotion, but did show a deficit in a more difficult task which only showed the eye region of the face, and which involved more subtle emotional states (Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997).

This task would be most useful as a measure of emotion recognition if it was appropriate for individuals across a range of abilities. For this reason, the level of correlation with IQ scores is of interest. Some correlation with IQ is perhaps unavoidable, but the results from the adolescent sample indicate only a slight positive correlation, indicating that the task is likely to be robust across a range of abilities. It is possible that this correlation was driven by a few individuals with a very low IQ performing very poorly on the task.

The positive correlation with social and communicative ability is what might be predicted given the importance of emotion recognition in everyday social interaction

and communication. Similarly, the negative correlation with age might be evidence of a 'pubertal dip' in emotion recognition ability (McGivern, Andersen, Byrd, Mutter & Reilly, 2002). Puberty data were not available from the sample to test this hypothesis. However, like the correlations with IQ, both of these correlations were only very slight, so should be interpreted with some caution.

One limitation which arose during the development of this test was the need to create a test of limited duration, in order to administer it within the strictly limited time available for testing the epidemiological sample. This meant that each animation could only be shown a certain number of times, and therefore participants could not be asked about all possible alternative emotions for each animation. As some pairs of emotions are more easily distinguished than other pairs, it is possible that the pairings for certain emotions were easier than others. A further consequence of the time constraints is that the recognition score for each emotion is based on a limited number of stimuli, and thus the extent to which it can be generalised to other stimuli is unclear.

In the studies described in the subsequent chapters of this thesis I use the animations developed in this study to further investigate the brain basis of emotion recognition, and its disruption in autism. First, I use the animations in a functional imaging study, together with other cues of emotion (facial expressions and vocalisations). Second, I use the animations as part of a test of emotion and animacy recognition in a sample of high-functioning adults with autism.

Chapter 5 Emotion recognition from social movement: an fMRI study

5.1 Introduction

In the study described in chapter 4, I demonstrated that social movement patterns alone were sufficient to give an impression of emotion. The brain mechanisms which enable emotion recognition from such abstract stimuli have not previously been investigated. The brain basis of emotion recognition has been studied extensively, but such studies have largely focussed on the recognition of emotion from facial expressions and, to a lesser extent, vocalisations. In the study described in this chapter I used fMRI to look for brain regions involved in the recognition of emotion from the animated stimuli described in chapter 4. The aim was to compare the brain areas used to process these animations with those used to process the more commonly investigated cues of emotional expression (faces and vocalisations).

As described in the introduction to this thesis, lesion and functional imaging studies have implicated a number of brain regions in the processing of expressions of emotion. The most extensively investigated of these is the amygdala, which is consistently activated in response to facial expressions of emotion (Breiter et al., 1996; Morris et al., 1996; Martin & Weisberg, 2003; Britton, Taylor, Sudheimer & Liberzon, 2006). The emerging picture is that the amygdala plays a perceptual role in emotion processing, prior to the completion of the emotion recognition process elsewhere in the brain (Winston, O'Doherty & Dolan, 2003). The amygdala appears to be specialised for the detection of emotionally salient stimuli (LeDoux, 2000) including threat signals (Adolphs et al., 1999) and may act to enhance cortical processing of such stimuli (Vuilleumier, Richardson, Armony, Driver & Dolan, 2004), and direct attention to salient facial regions (Adolphs et al., 2005).

Various temporal and temporo-occipital regions are also involved in emotion recognition. Several studies have demonstrated that activity in the fusiform gyrus (in particular, the fusiform face area) is modulated by the emotional expression of a face (Vuilleumier, Armony, Driver & Dolan, 2001; Winston, O'Doherty, & Dolan, 2003).

Also implicated in emotion recognition is the superior temporal sulcus (STS) region (Allison, Puce & McCarthy 2000), incorporating the STS proper, together with adjacent cortex in the superior temporal gyrus (STG) and middle temporal gyrus (MTG). These regions have been implicated in many aspects of social perceptual processing (see Allison et al., 2000 for a review), including processing the dynamic, changeable aspects of a face such as gaze direction and emotional expression (for review see Haxby, Hoffman, & Gobbini, 2002), and also more subtle social tasks such as the judgement of trustworthiness (Winston, Strange, O'Doherty & Dolan, 2002). The STS is activated by emotional facial expressions (Phillips et al., 1998), and is also activated when a person judges the emotion of a face, compared to when performing a control task such as judging identity (Streit et al., 1999; Narumoto, Okada, Sadato, Fukui & Yonekura, 2001). The temporal pole has also been implicated in emotion recognition, showing activation in response to facial expressions of both positive (Tsukiura et al., 2003) and negative (Blair et al., 1999) emotions. I aimed to investigate which of these temporal regions were involved in modality-general emotion recognition, and which might be sensitive specifically to facial cues.

Finally, several studies of emotion recognition have revealed involvement of the inferior frontal gyrus (IFG). The IFG tends to show an effect of task, being activated by explicit emotion recognition tasks more than by control tasks such as judging the gender (Gorno-Tempini et al., 2001) or attractiveness (Nakamura et al., 1999) of the face, or the colour of the background (Nakamura et al., 1999). This effect has been found in posterior regions of the IFG – the pars triangularis/pars opercularis (Nakamura et al., 1999; Gorno-Tempini et al., 2001), and also more anteriorly in the pars orbitalis (Nakamura et al., 1999).

In this study I aimed to investigate which of the aforementioned brain regions are also involved in the recognition of emotion from observed movement patterns. For all of these areas, there is some evidence of activation by non-facial cues to emotion. The amygdala and FFA are both activated by fearful body postures (Hadjikhani & de Gelder, 2003), and the amygdala is also activated by fearful vocalisations (Phillips et al., 1998). With regard to the other identified the other components of the emotion recognition network, the STS/STG region and IFG, there is also reason to predict that they might be involved in the recognition of emotion from movement patterns as

conveyed by the animations: the IFG because it is activated by attention to an emotion-recognition task, rather than emotion expressions per se, and the STG because it appears to be involved in emotion recognition from stimuli other than faces. Phillips et al. (1998) investigated the implicit processing of two emotions, fear and disgust, from both facial expressions and vocalisations. The only region involved in the processing of both emotions in both modalities was the STG. Although no study to date has specifically investigated emotion recognition from animations, animated stimuli that elicit mental state attribution, including emotion, activate the STS (Castelli et al., 2000; Schultz et al., 2003), and it has been hypothesised that the STS is particularly sensitive to moving stimuli (e.g. Beauchamp, Lee, Haxby & Martin, 2002).

To facilitate direct comparison between different cues to emotion, this study involved three types of stimulus: the abstract animations described in chapter 4, facial expressions from a standardised set (Ekman & Friesen, 1976) and non-verbal vocalisations (Warren et al., 2006), which represented an additional type of natural and familiar cue to emotion. To investigate the effect of task, as well as stimulus, on brain activity, I included both an emotion recognition task and a control task for each type of stimulus. This allowed me to look at the interaction between task and emotion, i.e. the brain regions activated by emotional (relative to neutral) stimuli when subjects were instructed to attend to the emotional content of the stimulus compared with when they were instructed to attend to some non-emotional stimulus attribute. I also investigated the interaction between emotion and modality, to see whether some brain regions were more strongly involved in emotion recognition from these abstract animations than the more familiar stimuli of faces or voices.

5.2 Methods

5.2.1 Participants

14 healthy adults (6 females; mean age 26.7±8.1) were recruited by advertisement. All had normal or corrected-to-normal vision, and were screened to rule out medication use and any history of neurological or psychiatric disorders. All participants gave written informed consent, and the study was approved by the local ethics committee.

5.2.2 Design

The design of this mixed blocked/event-related fMRI experiment was a 2x2x3 factorial with factors stimulus (emotional, neutral), task (emotion recognition, control), and modality (animation, face, voice).

5.2.3 Stimuli

The animations were taken from the set used in the study described in chapter 4, and featured two shapes: a black outline triangle and a black outline circle, moving on a white background. The movement of the shapes was designed to elicit the attribution of an emotion to the triangle – either anger, happiness, sadness or fear. Additional animations were created to give four different exemplars of each emotion. In addition, four 'neutral' animations were created, each of a similar length as the emotional animations. In these animations, the triangle was designed to appear living, but not to have a particular emotion.

Facial expressions were grayscale photographs taken from a standard set of pictures of facial affect (Ekman & Friesen, 1976). Participants saw photographs of four different individuals: 2 males and 2 females. Photographs of angry, happy, sad, fearful and neutral faces were included for each individual. During scanning, photographs were displayed to the participant for 1.5 seconds each.

Voices were also designed to convey the emotions of angry, sad, happy and fearful and were taken from a set used in a previous study (Warren et al., 2006). These were non-verbal vocalisations, of mean duration 1.3 seconds. The neutral stimuli were also non-verbal vocalisations, of similar duration. As with the faces and animations, there were four different exemplars of each emotion, and as with the faces, half of the voices were male, and half female. Whilst the sounds were played a central fixation cross was displayed on a blank screen.

In addition to these three types of stimulus there was also a baseline condition, in which a central fixation cross was displayed on a blank screen for 1.5 seconds.

5.2.4 Task

Whilst in the scanner, participants performed one of two tasks. Prior to the onset of each stimulus, a question was presented on the screen for 500 milliseconds. In the *emotion task*, the question 'Which EMOTION?' was presented, indicating to the participant that their task was to judge the emotion in the ensuing animation, photograph or voice (Figure 8). After the presentation of the stimulus, two alternative responses (emotion words) were then presented on the screen, one correct and one incorrect, and the participant had 2 seconds to select their response with a keypress.

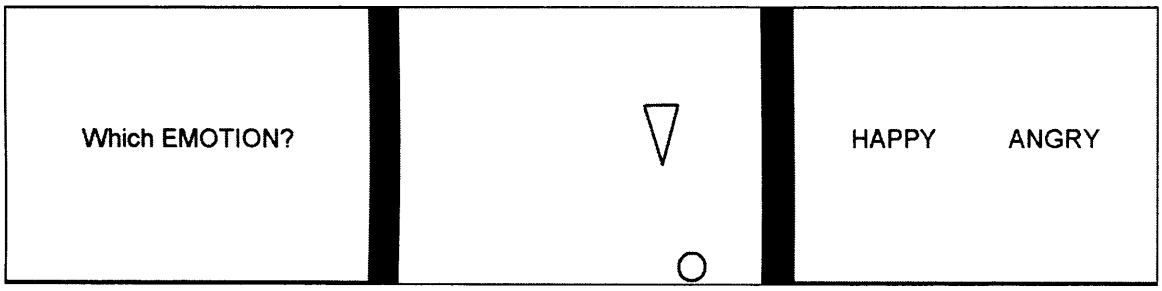

Figure 8. Sequence of screens shown to the participant during scanning. There were three types of stimulus: animations, faces and voices. The above example is from a trial featuring an animation. Animations were approximately 5 seconds in duration, and participants had 2 seconds after each animation to select one of two possible responses.

The *control task* varied according to the stimulus. For the animations, participants judged in which half of the screen (top or bottom) the triangle spent most of its time. For the photographs and voices, participants judged the gender of the face or voice. Before each stimulus, the participant was shown the question 'Which HALF?', or 'Which GENDER?', as appropriate, for 500ms. After the stimulus, two alternative responses were presented on the screen (either 'male' and 'female' or 'top' and 'bottom') and the participant had 2 seconds to respond.

The study was blocked by task, with each participant completing 20 blocks of the emotion task, and 20 blocks of the control task. Within each block, subjects were presented with two faces, two animations, two voices, and two baseline fixation events. These occurred in a pseudorandom order within each block, counterbalanced across blocks. Blocks of the two types occurred alternately, and this was counterbalanced across subjects, so that half of the subjects started with an emotion block and half with a control block.

5.2.5 Data acquisition

I acquired gradient echo T2*-weighted echo-planar images (EPIs) with blood oxygen level dependent (BOLD) contrast on a Siemens Allegra 3.0 Tesla MRI scanner, equipped with a transmit-receive quadrature head coil (repetition time [TR] = 2.6s, echo time [TE] = 30ms, flip angle = 90°, slice thickness = 2mm, interslice gap = 1mm, slices per volume = 40, in-plane resolution = 3mm, voxel size = 3x3x2mm). Each subject was scanned over 2 sessions, each lasting 14 minutes. 320 volumes were collected per session; these included six 'dummy' volumes at the start of each session, which were discarded to remove T1 saturation effects. Slices were angled to ensure coverage of the entire cerebral hemispheres. On average, slices were angled at approximately -12 degrees. A T1-weighted structural image was also acquired for each participant.

5.2.6 Image preprocessing

Analysis of the imaging data used SPM2 (http://www.fil.ion.ucl.ac.uk/spm/software/spm2) implemented in MATLAB 6.5 (Mathworks Inc, Sherborn, MA). Image preprocessing involved realignment and unwarping, spatial normalisation into MNI space, and spatial smoothing (6mm full width half maximum Gaussian kernel).

5.2.7 Statistical analysis

The analysis of the functional imaging data entailed the creation of statistical parametric maps representing a statistical assessment of hypothesised condition-specific effects (Friston et al., 1995). Only the scans corresponding to the duration of presentation of the stimuli were included in the analysis. Low-frequency sine and cosine waves modelled and removed subject-specific low-frequency drifts in signal, and global changes in activity were removed by proportional scaling. Condition-specific effects were estimated with the General Linear Model using a mixed event-related / block model. Three event types were modelled: stimulus modality

(animations, faces, voices); emotion (emotional, neutral) and fixation cross. In each block subjects performed either the emotion recognition task or the control task.

Random effects statistical analysis was undertaken in two stages. In the first stage, event types for each session were modelled by convolving onset times with a canonical haemodynamic response function. Parameters for each regressor were estimated using a subject-specific model. Linear contrasts were used to obtain subject-specific estimates for each of the effects of interest. These estimates were entered into the second stage of analysis treating subjects as a random effect, using one-sample *t* tests across subjects.

Statistical analysis was performed to examine the main effect of experimental conditions compared with fixation, the main effect of emotional stimulus versus neutral stimulus (ES-NS) for each stimulus modality type (animations, faces and voices), and the main effect of emotional task versus control task (ET-CT) for each stimulus modality type. I modelled the interactions between stimulus and task [(ESET-NSET) – (ESCT-NSCT)] for each stimulus modality type. This contrast was inclusively masked with a simple effects contrast (ESET-NSCT), to ensure that surviving interactions were in a meaningful direction. I also modelled the interaction between modality and emotion [e.g. (Emotional Animations – Neutral Animations) – (Emotional Faces – Neutral Faces)], to look for brain regions preferentially activated by the emotion versus neutral contrast for animations compared to other modalities. In this case, a simple effects contrast was used as a mask to ensure that the voxels activated by this interaction discriminated between emotional and neutral stimuli for the modality in question (so for the example above, the contrast of (Emotional Animations – Neutral Animations was used as a mask). Finally, I conducted a conjunction analysis on the main effect of emotion (ES-NS), and the main effect of task (ET-CT) across all three stimulus types.
Statistical contrasts were used to compute a t-statistic for each voxel within the brain, which was transformed into a map of Z-values and thresholded at $P<0.05$ (false detection rate corrected). I report regions that survive FDR correction (Benjamini & Hochberg, 1995; Genovese, Lazar, & Nichols, 2002), with a minimum cluster size of 10 voxels, apart from in the conjunction analyses, in which all uncorrected p-values smaller that 0.001 are reported. In addition, for the main effect of emotion and the

interaction between emotion and task, I report activations which survive small-volume FDR correction for the amygdala. As in chapter 3 of this thesis, the region of interest mask used in this correction encompassed all subnuclei of both amygdalae, and was created using the SPM Anatomy toolbox (Eickhoff et al., 2005) which, for the amygdala, is based on cytoarchitectonic probabilistic maps (Amunts et al., 2005). Results tables show the voxel of peak activity within each cluster.

5.3 Results

5.3.1 Behavioural data analysis

Throughout scanning, participants alternated between the control task, and the emotion recognition task. In each case, they had to watch the stimulus, and then select the correct response from one of two alternatives, using a keypress. Accuracy of each participant was assessed by computing the percentage of correct responses. Mean accuracy of participants on the emotion recognition task was 84.3% (s.d. = 8.59), and mean accuracy on the control task was 83.2% (s.d. = 8.38). In both tasks, all participants performed above the 50% that would be expected by chance. Across participants, scores were comparable across the different emotions for both the emotion task and the control task, with the exception of judging the gender of an angry voice, in which scores were lower, as revealed by a significant interaction between task, emotion and modality in a 2x5x3 ANOVA ($F_{(8,104)} = 3.750$, $p= 0.001$). This was perhaps because female voices are lowered when angry. A breakdown of the scores for individual modalities is shown in Table 3.

	Angry	Happy	Sad	Fearful	Neutral
Emotion task					
Animations	94	88	91	81	84
Faces	76	95	82	95	89
Voices	75	79	87	77	73
Control task					
Animations	97	77	92	68	91
Faces	95	93	94	93	95
Voices	54	89	76	63	73

Table 3. Percentage of correct responses, averaged across participants, for each condition.

5.3.2 Experimental conditions compared with baseline

As expected, the contrast of all experimental conditions (in which visual or auditory stimuli were presented and subjects made button press responses) vs. baseline fixation crosses resulted in significant activations in regions involved in visual, motor and language processing. These included the superior, middle and inferior occipital gyri, lingual gyrus, calcarine gyrus, cuneus, fusiform gyrus, superior and inferior parietal lobules, inferior temporal gyrus, superior frontal gyrus, precentral gyrus, postcentral gyrus, insula, thalamus, hippocampus and cerebellum.

5.3.3 Main effect of emotion (ES-NS)

This contrast evaluated regions activated by emotional relative to neutral stimuli, independent of task. A distinct set of brain regions was activated by this contrast in each of the three modalities. For animations, voxels were activated in the middle occipital/posterior middle temporal region, the precentral gyrus, the posterior STG, and bilaterally in the superior and inferior parietal lobes. For faces, activated voxels were predominantly within ventral occipital regions, namely the calcarine and fusiform gyri, with some activation of the superior parietal and inferior temporal lobes. For voices, the contrast revealed activations in superior temporal and inferior occipital cortex. The conjunction analysis revealed no voxels commonly activated by this contrast in all three modalities. However, in some brain regions voxels showed a main effect of emotion in more than one modality, as shown in table 4.

The region-of-interest analysis for the amygdala revealed a significant main effect of emotion in the right, but not left, amygdala for face stimuli (coordinates of peak

activation = 32 -2 -38, Z = 4.57). There was no activation of the amygdala for this contrast for animations or for voices.

Region	Animations		Faces		Voices	
	x y z	Z	x y z	Z	x y z	Z
Superior temporal gyrus (right)					62 -2 -6	5.52
Posterior superior temporal gyrus (left)	-50 -34 22	4.74			-42 -28 8	3.93
Posterior superior temporal gyrus (right)	64 -32 18	3.92				
Superior temporal sulcus (left)					-62 -26 -2	5.68
Posterior middle temporal gyrus (left)	-50 -68 2	5.82				
Posterior middle temporal gyrus (right)	54 -66 -2	6.04				
Inferior temporal gyrus (left)			-44 -20 -24	3.70		
Superior frontal gyrus (left)	-22 -4 60	4.36				
Superior frontal gyrus (right)	26 -2 62	4.19				
IFG pars orbitalis (left)	-42 46 -14	3.80				
IFG pars triangularis (left)					-42 18 24	4.09
IFG pars opercularis (right)	62 14 22	4.73				
Calcarine gyrus (left)	4 -92 -8	3.59	2 -92 6	5.76		
Precentral gyrus (left)			-48 2 38	3.18		
Postcentral gyrus (left)	-62 -2 30	3.64				
Superior parietal lobule (left)			-24 -62 54	3.83		
Superior parietal lobule (right)	24 -58 64	6.47	24 -56 56	3.28		
Supramarginal gyrus (left)	-58 -28 36	5.35				
Supramarginal gyrus (right)	52 -28 38	3.23				
Thalamus (left)	-16 -30 -2	3.93				
Middle occipital gyrus (left)	-28 -94 16	4.41				
Middle occipital gyrus (right)	32 -92 8	3.73				
Inferior occipital gyrus (left)					-20 -98 -12	5.03
Inferior occipital gyrus (right)					24 -96 -8	4.54
Fusiform gyrus (right)	32 -2 -38	3.91	32 -2 -38	4.57		
Cerebellum (right)			18 -52 -22	3.40	18 -50 -24	4.42

Table 4. Coordinates and Z-values for voxels activated by the main effect of emotional vs neutral stimuli. $p_{(FDR)} < 0.05$, minimum cluster size =10 voxels.

5.3.4 Main effect of task (ET-CT)

This contrast revealed areas that were activated by the emotion task relative to control task, independent of stimulus type. A conjunction analysis was performed across modalities. Significant activation was found in the left IFG pars orbitalis, the right IFG pars triangularis, the left insula, the left superior medial gyrus, STS, and inferior occipital gyrus, and in the right cerebellum (see table 5 and figure 9).

Region	x y z	Z	voxels
IFG pars orbitalis (left)	-46 38 -8	4.22	831
IFG pars triangularis (right)	58 34 12	3.87	181
Insula (left)	-30 24 -2	3.55	20
Superior medial gyrus	0 30 58	3.58	23
Superior temporal sulcus (left)	-56 -30 -4	3.61	14
Inferior occipital gyrus (left)	-44 -62 -12	3.26	21
Cerebellum (right)	10 -78 -34	3.88	49

Table 5. Coordinates and Z-values for voxels activated by the conjunction across modalities of the main effect of emotion recognition vs control task. $p_{(unc)} < 0.001$, minimum cluster size = 10 voxels

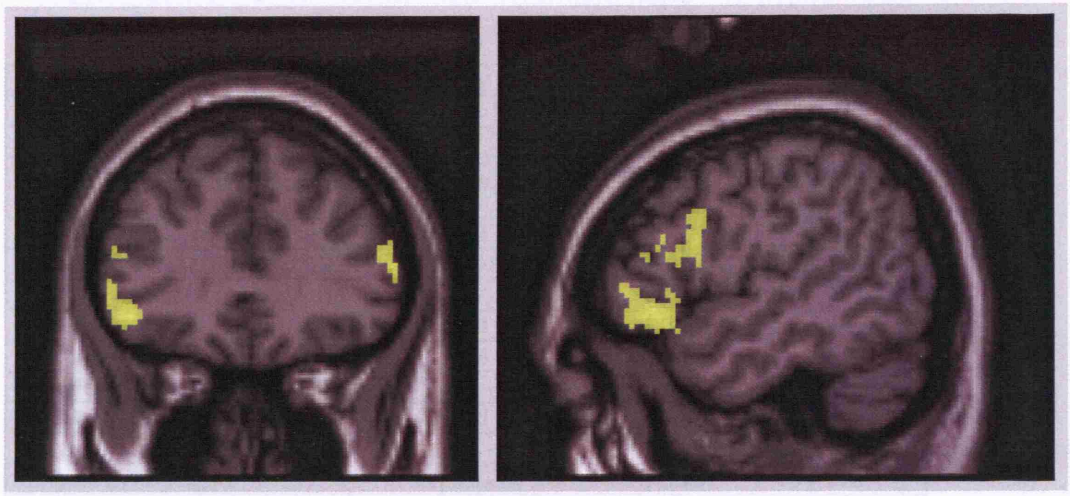

Figure 9. Brain regions activated by the conjunction across modalities of the main effect of task (image thresholded at $p<0.001$, slices taken at x=-50, y=33). Voxels were activated in the right inferior frontal gyrus (IFG) pars triangularis and the left IFG pars orbitalis in all three modalities

5.3.5 Interaction between emotion and task [(ESET-NSET) – (ESCT-NSCT)]

This contrast looked for brain regions activated by emotional (relative to neutral) stimuli in the context of attending to the emotional content of the stimulus compared with attending to some non-emotional stimulus attribute. For animations and vocal stimuli, no activations survived FDR correction. For faces, however, a significant interaction between emotion and task was found in many brain regions, including the IFG pars triangularis and pars orbitalis, and the STS and adjacent gyri (see table 6). The masking procedure and inspection of the activation patterns confirmed that these regions showed the predicted pattern of interaction, i.e. that the interaction was driven by a heightened response to emotional stimuli during the emotion recognition task.

The region-of-interest analysis for the amygdala for this contrast revealed significant bilateral activation of the amygdala for face stimuli (left: coordinates = -14 -10 -16, Z=3.65; right: coordinates = 26 -8 -20, Z = 4.15). There was no activation of the amygdala for this contrast for animations or for voices.

Region	x y z	Z	voxels
Middle frontal gyrus (right)	38 58 14	3.76	13
IFG pars orbitalis (right)	50 28 -6	3.72	107
IFG pars triangularis (left)	-42 24 22	4.36	426
IFG pars triangularis (right)	44 32 16	4.53	769
Superior medial gyrus	0 32 42	3.70	23
Precentral gyrus (right)	6 18 58	4.04	292
Superior parietal lobule (right)	36 -56 58	3.35	10
Superior occipital gyrus (left)	-24 -76 42	3.47	10
Middle occipital gyrus (left)	-36 -84 4	3.65	355
Middle occipital gyrus (right)	32 -72 28	4.05	31
Inferior occipital gyrus (left)	-28 -78 -6	4.03	74
Inferior occipital gyrus (right)	38 -84 -12	3.38	14
Lingual gyrus (right)	16 -78 -10	3.85	172
Fusiform gyrus (right)	32 -62 -18	3.52	32
Superior temporal sulcus (right)	48 -30 -2	3.61	64
Middle temporal gyrus (left)	-52 -38 0	3.59	15
Posterior middle temporal gyrus (left)	-44 -68 6	3.98	46
Posterior middle temporal gyrus (right)	52 -66 4	3.66	37
Inferior temporal gyrus (right)	46 -64 -10	3.92	156
Hippocampus (left)	-32 -22 -12	4.51	82
Hippocampus (right)	26 -10 -20	4.51	133
Parahippocampal gyrus (left)	-16 -34 -8	3.31	17
Caudate nucleus (left)	-18 -10 20	3.55	10
Cerebellum (left)	-10 -76 -36	4.49	303
Cerebellum (right)	42 -46 -28	3.66	61
Angular gyrus (right)	30 -62 42	4.17	57

Table 6. Coordinates and Z-values for voxels activated by the interaction between emotion and task for face stimuli. $p_{(FDR)} < 0.05$, minimum cluster size = 10 voxels.

5.3.6 Interaction between emotion and modality

As the contrast of emotional versus neutral stimuli revealed some activations only in response to one modality, I investigated this more formally by measuring the interaction between emotion (emotional stimuli vs. neutral stimuli) and modality (animations vs. faces), specifically to see which areas were activated more strongly in the emotion vs neutral contrast for animations than for faces. This interaction was repeated for the contrast of animations vs. voices. Table 7 shows the voxels activated by these contrasts. The posterior MTG, middle occipital gyrus, superior frontal gyrus and regions of the superior parietal lobe showed a significant interaction between emotion and modality, being activated more strongly by the emotional vs neutral contrast for animations than faces or voices (figure 9). The interaction between emotion and modality for animations vs. faces also activated the posterior STG, superior parietal lobule and superior occipital gyrus. The interaction for animations vs

voices also activated the right middle frontal gyrus, precentral gyrus and IFG pars opercularis, and the left inferior parietal lobule and cuneus.

	Animations (emotion vs neutral) vs Faces (emotion vs neutral)		**Animations (emotion vs neutral) vs Voices (emotion vs neutral)**	
Region	**x y z**	**Z**	**x y z**	**Z**
Posterior superior temporal gyrus (left)	-50 -36 22	4.70		
Posterior superior temporal gyrus (right)	62 -30 12	3.75		
Posterior middle temporal gyrus (left)	-50 -68 2	6.26	-50 -68 2	7.33
Posterior middle temporal gyrus (right)	54 -66 -2	6.03		
Inferior temporal gyrus (right)			54 -68 -4	7.02
Superior parietal lobule (left)	-16 -74 54	3.93		
Superior parietal lobule (right)	40 -46 58	4.91		
Inferior parietal lobule (left)			-58 -26 44	5.18
Precentral gyrus (right)			50 -8 54	3.01
Supramarginal gyrus (left)	-56 -28 38	4.48		
Supramarginal gyrus (right)	64 -22 46	3.64	56 -28 46	4.11
Superior occipital gyrus (right)	26 -76 44	3.81		
Middle occipital gyrus (left)	-28 -84 40	4.12	-28 -82 38	6.58
Middle occipital gyrus (right)			34 -80 34	6.76
Cuneus (left)			-8 -100 16	6.17
Superior frontal gyrus (left)			-22 -2 64	2.98
Superior frontal gyrus (right)	26 0 56	3.84		
Middle frontal gyrus (right)			28 -4 52	3.32
IFG pars opercularis (right)			56 10 24	3.03
Rolandic operculum (right)			46 -28 20	2.73

Table 7. Coordinates and Z-values for voxels activated by the interaction between modality and emotion, for animations versus faces and animations versus voices. $p_{(FDR)} < 0.05$, minimum cluster size = 10 voxels.

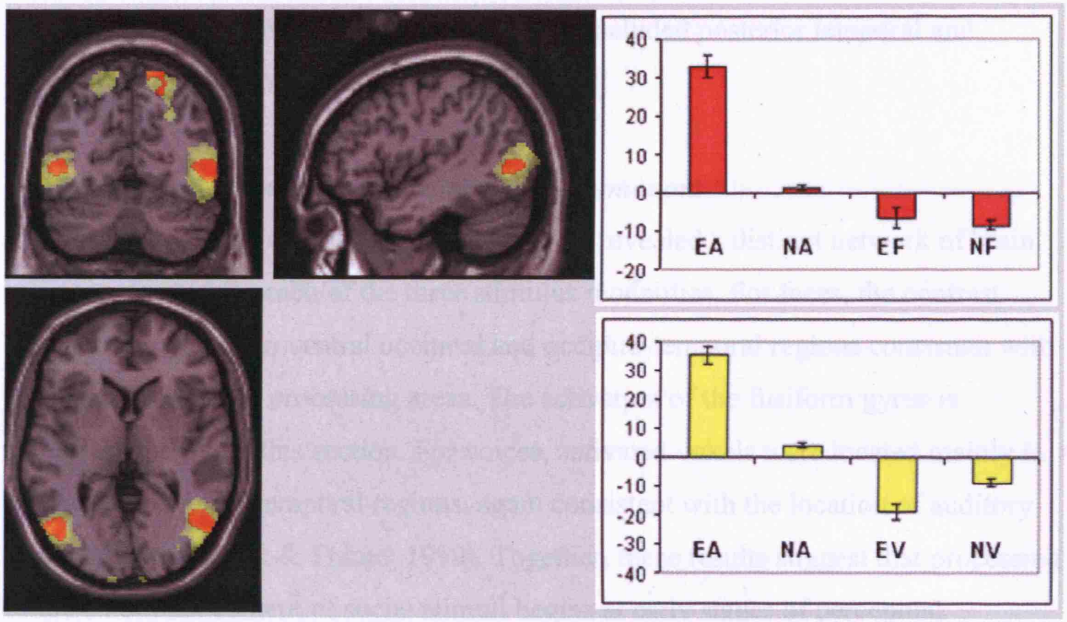

Figure 10. Brain regions activated by the interaction between emotion and modality for animations versus faces (red blobs, upper graph) and animations versus voices (yellow blobs, lower graph), after application of an inclusive mask of (Emotional Animation – Neutral Animation). Image thresholded at $p<0.05$, slices taken at x=-44, y=-66, z=3. Graphs show the parameter estimates for the relative percentage BOLD signal in the voxel of maximum intensity of activity in the left posterior MTG (coordinates -50 -68 2). Voxels in the right posterior MTG showed a similar pattern. Error bars indicate 1 standard error either side of the mean. For z-values see table 7. (EA = emotional animations, NA = neutral animations, EF = emotional faces, NF = neutral faces, EV = emotional voices, NV = neutral voices.)

5.4 Discussion

In the study described in this chapter, I investigated the neural processing associated with a novel set of animations designed to evoke, from the pattern of interaction between two abstract shapes, the attribution of emotion. I compared activations to these animations with activations associated with two conventional types of emotional stimulus: faces and voices. In addition, I manipulated the task that subjects performed: subjects were instructed to attend either to the emotion portrayed by the stimulus or to a non-emotional attribute of the stimulus. I found that the brain regions activated by emotional relative to neutral stimuli varied depending on the modality of the stimuli, with emotional animations eliciting activation of motion-sensitive regions of the posterior temporal and superior parietal cortices. The main effect of task (attending to the emotional aspect of a stimulus relative to a non-emotional attribute) activated the IFG in all three stimulus modalities. The interaction between modality and emotion revealed brain areas that might be preferentially involved in the

processing of emotion from animations, which included posterior temporal and superior parietal regions.

The neural basis of emotion recognition from animations

The contrast of emotional versus neutral stimuli revealed a distinct network of brain regions activated for each of the three stimulus modalities. For faces, the contrast revealed activations in ventral occipital and occipito-temporal regions consistent with the location of visual processing areas. The activation of the fusiform gyrus is discussed later on in this section. For voices, activated voxels were located mainly in superior and middle temporal regions, again consistent with the location of auditory cortex (Kaas, Hackett & Tramo, 1999). Together, these results suggest that processing of the emotional content of social stimuli begins at early stages of perceptual processing of these stimuli. This could be verified by investigating the temporal patterns of the brain's response to emotional versus neutral stimuli using event related potentials. Early results from such studies indicate that differences in the ERP response to faces of different emotional expression occur as early as 140ms after presentation of the faces (Kiss & Eimer, 2007), though this difference could of course reflect subcortical rather than cortical processing of the stimuli.

Consistent with this idea, the contrast of emotional versus neutral animations elicited activation of the posterior MTG, which is the location of the visual motion processing region MT/V5 (Zeki et al., 1991). The middle occipital gyrus was also activated by this contrast, possibly reflecting activity in the visual motion processing area V3a. These two regions were also activated in the interaction between emotion and modality, lending further weight to the idea that their response to emotional stimuli is specific to the animations.

These findings suggest that the recognition of emotion from movement patterns might be a process that begins early on in motion perception, and that the processing of moving stimuli at these early stages might be subject to top-down influences if these stimuli are deemed to be emotionally interesting. It is difficult to draw firm conclusions about whether the enhanced response to emotional animations was due to top-down influences, as the contrast for the interaction between task and stimuli for

animations did not reveal activation of these regions when corrected at the whole-brain level.

However, it is important to consider alternative explanations of these findings. It is possible that there was more movement in the emotional stimuli than the neutral stimuli, and that therefore the activation of area MT/V5 was due simply to low-level properties of the movement. The stimuli were matched by eye in terms of total amount of movement, but a more formal analysis of the movement within the animations might be able to confirm whether or not this was the case. It is also possible that subjects paid more attention to the motion of the emotional stimuli than the neutral stimuli. This could have enhanced the activation within MT/V5 (e.g. see Buchel et al., 1998a).

An interesting comparison can be drawn between the activations elicited by emotional animations, and those elicited by dynamic facial expressions of emotion. Dynamic expressions of fear elicit activation of the posterior temporal lobe (Sato, Kochiyama, Yoshikawa, Naito and Matsumura, 2004) in a location very similar to that observed in this study. This occurs whether they are contrasted with static facial expressions, or with moving non-face stimuli. It provides further evidence that the activation of this region is not simply due to the low-level movement properties of the stimuli, but is influenced by their emotional content.

Emotional animations also elicited activation of parietal regions, such as the supramarginal gyrus, both in the main effect of emotion for this modality, and in the interaction between emotion and modality, showing that the response of these regions to emotional stimuli was especially pronounced for animations. These findings, together with the activations of MT/V5, are consistent with those of imaging studies investigating observed human motion (Schubotz & von Cramon, 2004; Wheaton et al., 2004; Manthey, Schubotz & von Cramon, 2003). As would be expected, observing human actions activates the visual motion-sensitive area MT/V5 (Schubotz & von Cramon, 2004; Wheaton et al., 2004). However, the supramarginal gyrus in the parietal lobe is also activated (Manthey et al., 2003). Moreover, this region appears to be particularly sensitive to movements which occur in the context of a meaningful action (Manthey et al., 2003), suggesting that motion processing in this region goes

beyond the low-level sensory properties of the observed movement, and might be to some degree hypothesis–driven, and subject to the influence of context. The activation of this region by the emotional animation might thus indicate the incorporation of contextual information and hypotheses about goals or intentions in order to identify the emotion present in the animation.

The activation of the superior parietal lobe in response to the emotional animations is consistent with the findings of a study into contingency and intentionality which used animated shapes (Blakemore et al., 2003). In this study, subjects watched two moving shapes, which varied in the extent to which their movement appeared animate, and contingent on the movement of the other shape. The superior parietal lobe was specifically activated in response to contingent, animate movement. As the perception of emotion in the animations relied on interactions between the triangle and the circle, this factor could explain the activation of the superior parietal lobule by the emotional animations in this study.

Involvement of the IFG in top-down processing of emotion

The conjunction analysis for the effect of task revealed that the IFG pars triangularis was activated by stimuli in all three modalities when subjects attended to emotion more than when they attended to some non-emotional attribute of the stimuli (figure 8). This is consistent with findings from previous studies using facial (Nakamura et al., 1999; Gorno-Tempini et al., 2001) and vocal (Imaizumi et al., 1997) stimuli, in which the emotion recognition task was contrasted with a control task, involving judging the gender (Gorno-Tempini et al., 2001) or attractiveness (Nakamura et al., 1999) of the face, the colour of the background (Nakamura et al., 1999), or the identity of the speaker (Imaizumi et al., 1997). Activation of the more anterior part of the IFG, the pars orbitalis, is similar to activation during emotion recognition tasks reported in earlier studies using faces (Nakamura et al., 1999; Winston et al., 2003) and voices (Wildgruber et al., 2005). It has been suggested that these two different parts of the IFG subserve different roles in emotion recognition, with Brodmann's area 45 (roughly corresponding to the IFG pars triangularis) being involved in the cognitive aspects of emotional judgement, whilst Brodmann's area 47 (which corresponds to the IFG pars orbitalis) is implicated in retrieving the reward value associated with emotional expressions (Schirmer & Kotz, 2006).

It is possible that the activation of the IFG by the emotion recognition task was due to incidental effects such as task difficulty: indeed, an effect of task in similar regions of the IFG has been found in studies using stimuli and tasks unrelated to emotion recognition (Frankenstein, Richter, McIntryre & Remy, 2001; Binder et al., 1999). In this study the emotion recognition task, in which participants had to keep five possible responses in mind, may have been more difficult than the control task, in which there were only two options. However, the behavioural scores do not indicate that participants found the emotion task more difficult. In addition to this, lesions to the frontal cortex (including the IFG) impair comprehension of vocal and facial emotional expressions (Hornak, Rolls, & Wade, 1996). Therefore it is likely that the IFG activation in the emotion recognition task reflects its involvement in top-down aspects of emotion recognition.

One possible complication when interpreting the effect of task is that the control task was necessarily different for the animations, as gender judgement could not be used. Therefore the subtraction of control task activity from emotion task activity does not isolate precisely the same cognitive processes for each type of stimulus. The requirements for the emotion task for animations may have differed from the control task in more ways than simply the need to recognise emotion. For example the shapes needed to be tracked for the duration of the animation for the emotion task but not for the control task, in which the subject could perform the task correctly by simply monitoring one half of the screen. Therefore the contrast of main effect of task might also isolate brain regions involved in movement perception and overt or covert tracking of stimuli. Similarly, the requirements of the emotion and control tasks for face stimuli might have differed in several ways – for example the regions of the face or the type of processing (featural versus configural) used in determining an individual's gender might be different from those used in determining the emotion displayed.

These differences in the cognitive processes isolated by the task comparison in each modality would present a potential confound were the areas showing a main effect of task for animations to be compared directly to those showing a main effect of task for the other stimuli. However, this comparison was not made in this study and the data

from these contrasts were used only in a conjunction analysis. The only process commonly isolated by all three contrasts would have been that of emotion recognition, so it is likely that the IFG activity reflects its involvement in this process.

Activation of the STS

Activation of the STS was found in the contrast of emotional versus neutral stimuli for voices, and in the interaction between emotion and task for face stimuli. Activation of the STS itself was not found in response to either of these contrasts for animated stimuli, though the STG, superior to the STS, was activated by the contrast of emotional versus neutral animations. These findings are consistent with other studies that have found activation of the STS and adjacent gyri by emotional stimuli. Previous studies have found activity in the STG for emotional faces (Britton et al., 2006), and in the MTG for emotional voices (Morris, Scott & Dolan, 1999; Johnstone et al., 2006). It should be noted that the activation of the STG in response to the animations in this study occurred more posteriorly than the activations found in these previous studies, and that in this study the precise location of activation on or adjacent to the STS was different in the different modalities of stimuli.

Other studies have found a main effect of task, rather than of stimulus, in the STS region. Narumoto et al. (2001) showed that the right STS was activated when subjects attended to the emotion in faces, compared with a control task. Similarly, posterior STS/STG was activated when subjects attended to the emotional content of speech sounds (Wildgruber et al., 2005). The findings of this study are consistent with these previous results, showing activation of the STS in the conjunction across modalities of the main effect of task.

The involvement of the STS in emotion recognition could be related to the fact that emotion recognition involves the consideration of another person's unobservable internal state. The STS has been implicated in other tasks that involve this process, such as mentalising, and activation in similar regions of the STS has been found in studies of mentalising (for a meta-analysis of such studies, see Frith & Frith, 2003).

Activation of the fusiform gyrus

The right fusiform gyrus (FG) was activated by the contrast of emotional versus neutral stimuli for faces. This is consistent with previous findings that FG activity is modulated by the emotional expression of the face. Vuilleumier et al. (2001) found that the FG response was greater to fearful than to neutral faces. Winston et al. (2003) found that the FG responded to high versus low intensities of emotional expression for four emotions (disgust, fear, happiness and sadness). However, the results from this study suggest that involvement of this area in emotion recognition is not restricted to faces since the FG was also activated by the main effect of emotion for animated stimuli. Similar results have been found in a previous study using animated geometric shapes (Schultz et al., 2003). It is not possible to ascertain whether the FG activation observed in the current study was within the fusiform face area (FFA) itself, as the location of this region within the FG varies among individuals and needs to be verified using a sequence of localiser stimuli as employed in the study described in chapter 3. However, a comparison with the coordinates of the regions assigned to the FFA in chapter 3 indicates that the region of the FG activated by animations and faces in the current study might be anterior and inferior to the FFA itself.

Activation of the amygdala

I found that the right amygdala was activated by the contrast of emotional versus neutral faces. This is in congruence with a number of previous studies (e,g. Vuilleumier et al., 2001; Pessoa et al., 2002), which have found an amygdala response to emotional faces when contrasted with neutral (but see Fitzgerald et al., 2006). It is also consistent with the results obtained in the study described in chapter 3 of this thesis. That the right, but not left, amygdala was activated is unusual, as discrepancies typically occur in the opposite direction (Wager et al., 2003).

I also found an interaction between emotion and task in the amygdala on both sides, again for face stimuli. This is consistent with other studies which have found a similar interaction (Gorno-Tempini et al., 2001; Pessoa et al., 2002; Williams et al., 2005), and provides further evidence for the involvement of the amygdala in the processing of emotional faces. The interaction indicates that processing in the amygdala might be subject to top-down influences, i.e. that its response to emotional faces is enhanced when attention is directed towards this aspect of the stimulus.

The lack of a main effect of emotion in the amygdala in response to the other stimulus modalities tested is in contrast to previous studies which have found amygdala activation in response to fearful vocalisations (Phillips et al., 1998) and body postures (Hadjikhani & de Gelder, 2003). Taken together, these results suggest that facial expressions are the stimuli which most reliably elicit amygdala activation, but do not rule out the possibility that an imaging study with more power might find activation in response to the animated and vocal stimuli used here.

Limitations

This study used the animations developed and validated in the study described in chapter 4. However, it should be noted that additional animations were created specifically for this study. These were not validated on the large epidemiological sample as in chapter 4, and therefore there is less certainty that they elicited the impression of the intended emotions. However, the animations were very similar to those used in the study described in chapter 4. In addition, the behavioural scores in this chapter indicate that fMRI subjects were able to identify the correct emotion present in the majority of animations. It is therefore likely that the emotional animations were indeed recognised as emotional by the subjects.

Summary

To summarise, the study described in this chapter investigated the brain basis of emotion recognition from abstract animations, compared to the more familiar stimuli of facial expressions and non-verbal vocalisations. I found evidence of involvement of the STS and adjacent gyri in the recognition of emotion from these stimuli, as well as involvement of the IFG in the top-down aspects of emotion recognition. Posterior temporal and superior parietal regions appeared to be specifically involved in emotion recognition from animations, compared with the other stimulus types. In the study described in the next chapter of this thesis, I further investigate the recognition of emotion from these animated stimuli by using them to test the emotion recognition ability of adults with high-functioning autism.

Chapter 6 Emotion recognition from social movement in autism

6.1 Introduction

In chapters 4 and 5 of this thesis I investigated the evocation of an impression of emotion from movement patterns, and used these movement-based stimuli in a functional imaging study to investigate the brain mechanisms responsible for their interpretation. The study described in this current chapter expands upon this work, by investigating the interpretation of these stimuli by individuals with autism. This was undertaken in the hope of gaining additional insight into the brain mechanisms of emotion recognition from these animated stimuli, as well as the nature of the emotion recognition deficit reported to exist in autism.

An introduction to the defining characteristics of autism, the variability of symptom severity, and other related disorders on the autism spectrum is given in chapter 1 of this thesis, in which I also summarise research into emotion recognition abilities in autism. Many studies have found emotion recognition deficits in autism (Hobson 1986a,b; Hobson, Ouston & Lee 1988b; Tantam et al., 1989; Bormann-Kischkel, Vilsmeier, & Baude, 1995; Lindner & Rosen, 2006), but overall the evidence is somewhat equivocal, with a number of studies showing negative findings (Ozonoff et al., 1990; Buitelaar et al., 1999; Castelli, 2005). Differences in testing paradigms and the matching of control samples are likely to contribute to these conflicting findings, and heterogeneity within the autistic population could also be an important factor.

As discussed in earlier chapters, many different personal cues can be used to recognise emotion, such as information from different parts of the face, tone of voice, gestures, and an individual's behaviour and interaction with others. If individuals with autism are indeed impaired in emotion recognition, it is as yet unclear whether their deficit affects the use of all cues, or is specific to certain cues such as facial expression. This will depend on the level of processing at which the purported emotion recognition deficit causes disruption. A deficit at the sensory/perceptual level, for example, would disrupt emotion recognition within certain modalities only.

In this study, I investigated emotion recognition in a group of adults with autism, and matched controls. I investigated emotion recognition from the animations described in chapters 4 and 5 of this thesis. For comparison, I also investigated emotion recognition from facial expressions, using stimuli from the same set of standardised pictures used in Chapter 5.

The first aim of this study was to investigate whether I could replicate earlier findings of an emotion recognition deficit in autism. The conflicting findings of earlier studies can be explained partially, though not wholly, by differences in matching of the control group. Ozonoff et al. (1990) observe that matching by verbal mental age (MA) is likely to be a more conservative approach than by overall MA or non-verbal MA since individuals with autism typically have a higher non-verbal than verbal MA. Broadly speaking, studies that have matched groups on non-verbal measures of MA (Hobson et al., 1986a,b; Tantam et al., 1989) found a deficit in the autism group, whilst among studies that matched according to verbal ability results are more mixed, with some (Hobson et al., 1988; Lindner & Rosen, 2006) but not all (Ozonoff et al., 1990; Castelli et al., 2005) studies finding evidence of impairment. In this study I observed stringent matching criteria, matching for verbal and non-verbal performance, and for chronological age, to investigate whether reported emotion recognition deficits would remain.

Secondly, I wished to investigate the nature of any existing deficit, i.e. which stimuli it was sensitive to, and thus what level of processing it might be occurring at. With regard to emotion recognition from facial expression, there is some evidence for an impairment in autism, and given the wealth of evidence for abnormal face processing in autism, one might hypothesise that these deficits arise at a perceptual level. In support of this is the finding that the fusiform face area is less active when individuals with autism perform a facial emotion matching task, compared to controls (Wang et al., 2004; Piggot et al., 2004). One might therefore predict that emotion recognition deficits would be restricted to facial stimuli.

To date there have been no emotion recognition studies in autism based on animated stimuli. However, individuals with autism do show deficits in the interpretation of movement patterns, for example in point light displays (Blake et al., 2003). Also,

animated stimuli have been used to test the attribution of other mental states. Abell et al. (2000) devised a set of four animations involving two triangles, the movement of which was designed to evoke mental state attributions. In contrast, in the four control animations, the triangles appeared to be taking simple goal-directed actions. The subject's task was to give a running commentary on the film, describing the actions of the triangles. Typically-developing children tended to attribute more complex mental states to the first set of animations than to the control animations. In the commentaries of children with autism, mental state descriptions were more likely to be inappropriate to the animation in question, compared with the control group. Castelli et al. (2002) found a similar response pattern in adults with high-functioning autism or Asperger syndrome. Given these known differences in the interpretation of animations in autism, one might predict that an emotion recognition deficit might manifest itself in the processing of animated stimuli.

The final aim of this study was to investigate the potential downstream consequences of any emotion recognition deficit. It has been proposed that social information processing, including the interpretation of facial expressions and body movements, is linked to social interaction deficits in autism (Joseph & Tager-Flusberg, 2004). I therefore tested the hypothesis that the interpretation of emotionally salient movement patterns, as measured in my task, would be related to an autistic participant's social reciprocity as assessed by the Reciprocal Social Interaction (RSI) subscale of the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000)[1].

6.2 Experiment 1: Emotion recognition from animations

6.2.1 Methods

6.2.1.1 Participants

Two groups of participants were recruited by advertisement in literature of national autism groups and societies: 11 individuals with autism (9 males, 2 females), and 11 typically developing controls (9 males, 2 females). The groups were matched for age

[1] Some of the results presented in this chapter have recently been published in a research article (Boraston, Blakemore, Chilvers & Skuse, 2007).

(see Table 8). All participants in the autism group had a diagnosis of autism, Asperger syndrome or autism spectrum disorder from a GP or psychiatrist. The diagnosis was confirmed by administering the Autism Diagnostic Observation Schedule (ADOS) (Lord et al., 2000). In total, 6 participants met the criteria for autism, and the remaining 5 for autism spectrum disorder. All participants gave informed consent, and the local ethics committee approved the study.

Group	Subject	Age (years)	Verbal IQ	Performance IQ
Autism	1	60.2	130	133
	2	59.4	126	103
	3	51.5	119	121
	4	33.2	112	103
	5	24.5	111	103
	6	24.4	109	121
	7	37.1	108	127
	8	37.1	132	135
	9	24.8	109	96
	10	32.4	121	137
	11	19.6	118	107
	Mean	36.7	118	117
Control	1	57.6	135	127
	2	59.8	127	124
	3	53.2	99	108
	4	31.4	89	85
	5	24.9	96	111
	6	24.4	115	116
	7	33.8	99	117
	8	36.4	109	111
	9	20.7	96	119
	10	32.8	119	127
	11	20.7	107	105
	Mean	33.8	108	114
	SD	13.2	14.4	12.0
	Group comparison	$t_{(20)} = 0.128$, NS	$t_{(20)} = 1.863$, NS	$t_{(20)} = 0.565$, NS

Table 8. Details of the autism and control groups. NS = non-significant ($p>0.05$).

The groups were matched for verbal and performance IQ, as measured by administering all four subtests of the Wechsler Abbreviated Scale of Intelligence (WASI). Full details of the two groups can be found in Table 8.

All participants were screened for exclusion criteria by self-report prior to taking part in the study. Those with dyslexia, epilepsy, or other neurological or psychiatric conditions were excluded. The screening process also included a short questionnaire, in which participants were required to give unambiguous definitions (as judged by the

experimenter) of the emotions under investigation: 'angry', 'happy', 'sad' and 'scared'. All participants were able to do this task without difficulty.

6.2.1.2 Design and procedure

The basic task design was identical to that described in Chapter 4, except with the incorporation of an additional condition. This was designed as a control, given the documented difficulties in the interpretation of animated stimuli in autism. To ensure that a low score in the task was due to failure to recognise the emotion in the animation, rather than a failure to interpret the shapes in the animation as living, an animacy detection condition was added. This necessitated the creation of four additional animations, in which the triangle moved in a manner designed to make it appear inanimate ('*non-living*'). For example, it might appear to be moving as if falling under gravity. The trajectory of movement of the circle was identical in both the original eight animations and these additional four. (Animations can be found at http://www.icn.ucl.ac.uk/sblakemore/).

These additional animations entailed a test slightly longer than that described in Chapter 4. This time, participants viewed each *living* animation three times, and each *non-living* animation once, making a total of 28 presentations, in a pseudorandom order. After each presentation of an animation, a question appeared on the screen. There were two types of question: 'emotion' questions, and 'living' questions.

'Emotion' questions were identical to those described in Chapter 4, and were of the format: 'was the triangle ANGRY?' For each *living* animation, an emotion question followed two of the three presentations. One of these referred to the actual emotion intended to be perceived in the animation. The other referred to an alternative emotion that was not intended to be perceived. Emotion questions were not asked for the *non-living* animations. Participants answered the emotion question using a rating scale from 0 ("not at all...") to 5 (extremely...").

'Living' questions were of the format 'was the triangle LIVING?' A living question followed each of the four *non-living* animations, and one presentation of each of the eight *living* animations. Each *living* animation was therefore shown twice with an

'emotion' question, and once with a 'living' question. Again for the 'living' question, the participant answered using a rating scale from 0 ("definitely non-living") to 5 ("definitely living"). The rating scale was explained to each participant before the experiment, and participants completed four practice trials.

6.2.1.3 Data analysis

Analysis of the responses to the 'emotion' question was identical to that described in Chapter 4. Four scores were generated for each participant, indicating recognition ability of each of the four emotions. For each emotion, scores across the two groups were then compared using a Mann-Whitney non-parametric test. Cohen's d (Cohen, 1988) was also calculated as a measure of effect size for each of the four emotions, independent of sample size. Cohen's d is obtained by dividing the difference between the two group means by the pooled standard deviation of the groups. For the 'living' question, there was no subtraction procedure to create a score. Instead the mean ratings of the two groups were compared for each of the emotional animations, and for the animations that were designed to appear inanimate, again using a Mann-Whitney non-parametric test.

6.2.2 Results

6.2.2.1 Animations: Emotion recognition task

Figure 11a shows how the autism and control groups rated each animation type for the actual and alternative emotions. As described in Chapter 4, these ratings were subtracted to give a score for each participant for each emotion. This was done because a difference score more accurately indicates how well each participant could identify the correct emotion for each animation.

Figure 11b shows these calculated scores for the two participant groups. Control participants scored higher than participants with autism for three of the four emotions. Scores for all conditions were greater than zero, indicating that both participant groups had some ability to distinguish the actual emotion label from the alternative one. Scores for individual participants are shown in table 9.

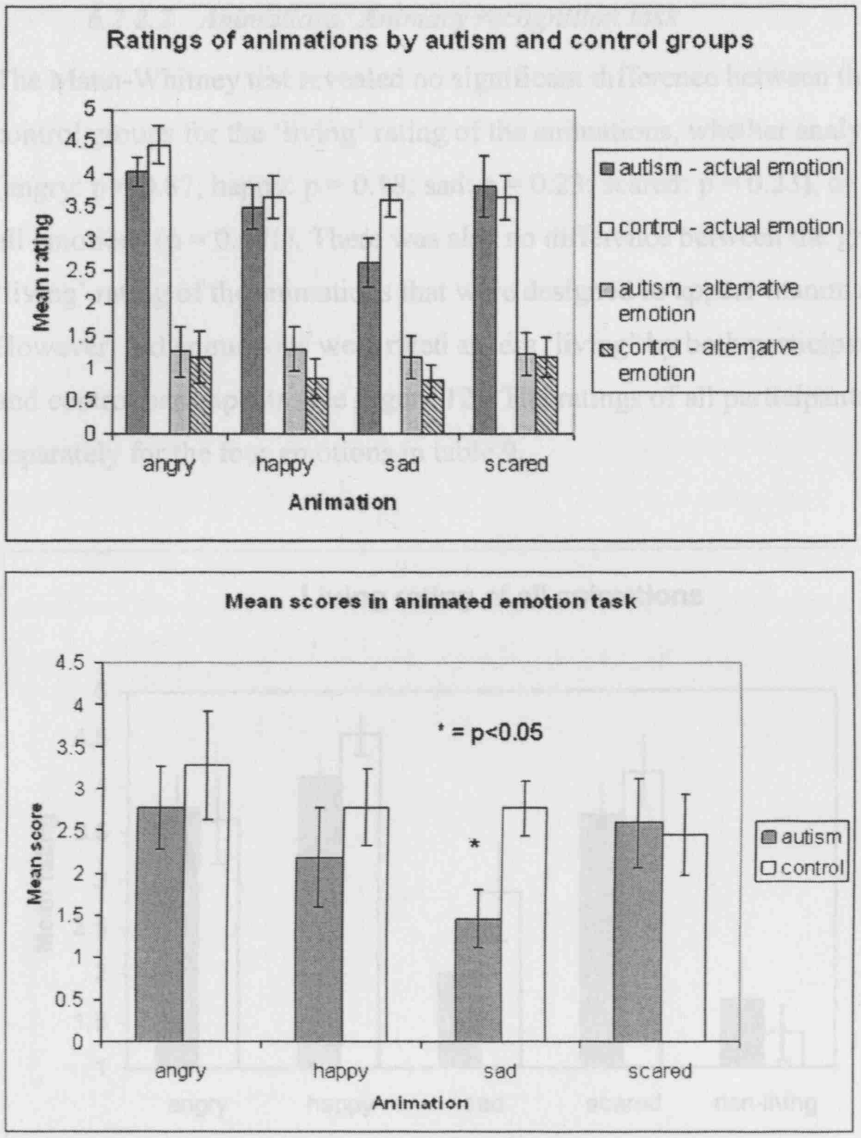

Figure 11. Mean ratings of the animations by the two participant groups, for either an actual or an alternative emotion (11a: top), and computed emotion recognition scores of the autism and control groups, on the animated emotion task (11b: bottom). The range of possible scores was from -5 to +5, with a higher score indicating a greater accuracy in correctly identifying the emotion. Error bars indicate standard error. * = $p<0.05$.

The Mann-Whitney tests revealed no significant difference between the groups for angry ($p = 0.32$), happy ($p = 0.35$) or scared ($p = 0.81$) animations, but a significant difference for sad animations ($p = 0.01$). These data are shown in **Figure 11**b. Table 9 shows that all of the control participants had higher sadness recognition scores than the mean score of the autism group. The calculated effect sizes revealed a large effect of group only for sadness ($d = 1.26$), a medium effect size for happiness ($d = 0.36$) and anger ($d = 0.28$), and almost no effect for fear ($d = 0.09$).

6.2.2.2 *Animations: Animacy recognition task*

The Mann-Whitney test revealed no significant difference between the autism and control groups for the 'living' rating of the animations, whether analysed separately (angry: $p = 0.87$; happy: $p = 0.18$; sad: $p = 0.23$; scared: $p = 0.23$), or together across all emotions ($p = 0.401$). There was also no difference between the groups for the 'living' rating of the animations that were designed to appear inanimate ($p = 0.40$). However, sad animations were rated as less 'living' by both participants with autism and control participants (see Figure 12). The ratings of all participants are shown separately for the four emotions in table 9.

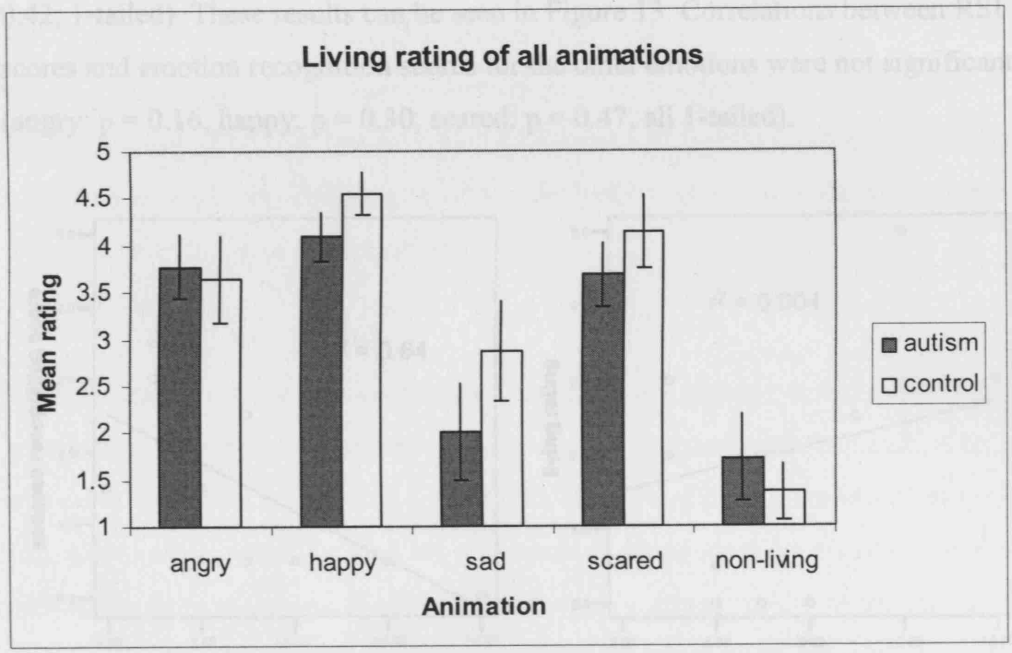

Figure 12. Mean 'living' ratings of the autism and control groups for animations representing each of the five types of animation. Error bars indicate standard error. Ratings are on a scale from 0 to 5.

6.2.2.3 *Task scores compared to degree of social impairment*

Module 4 of the ADOS (Lord et al., 2000) was used to confirm the diagnosis of each participant with autism, by assessing his or her behaviour in social interaction with the examiner. In this module of the ADOS, ratings of impairment are derived in terms of subscales measuring reciprocal social interaction (RSI), social communication skills, imagination/creativity and repetitive behaviour patterns. A higher score on a subscale indicates a greater degree of impairment.

For the participants with autism, I correlated emotion recognition performance with their social interaction skills as assessed by the RSI measure of the ADOS. A Spearman's non-parametric test was used to assess the correlation between each participant's score on the RSI scale, and his or her emotion recognition score from the animation task. As a comparison, I also assessed the correlation between the RSI scores and the mean 'living' rating of the sad animations. There was a significant negative correlation between magnitude of impairment on the RSI subscale and the sadness recognition score ($r^2 = 0.64$, $p = 0.002$, 1-tailed). Greater social impairment correlated with poorer recognition of sadness. There was no significant correlation between the RSI score and the 'living' rating of the sad animations ($r^2 = 0.004$, $p = 0.42$, 1-tailed). These results can be seen in Figure 13. Correlations between RSI scores and emotion recognition scores for the other emotions were not significant (angry: $p = 0.16$, happy: $p = 0.30$, scared: $p = 0.47$, all 1-tailed).

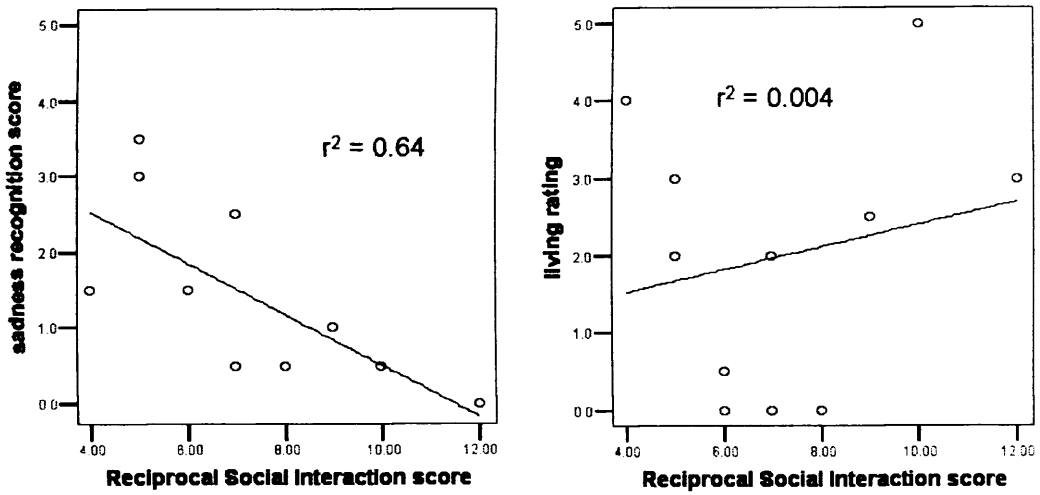

Figure 13. Scatterplots indicating correlation between a participant's RSI score (higher score = more impaired) and his or her ability to recognise that a 'sad' animated triangle is sad (left) or living (right).

6.3 Experiment 2: Emotional faces task

6.3.1 Methods

6.3.1.1 Participants

All 11 of the participants with autism from Experiment 1, and nine of the control participants (seven males), took part in this study (mean age of controls: 34 ±15.0 years, mean verbal IQ: 107 ±15.6, mean performance IQ: 112 ±12.5). Again, there

were no significant differences between the age and IQ distribution of the autism and control groups (age: t = 0.70, p = 0.945; verbal IQ: t = -1.8, p = 0.09; performance IQ: t = -0.73, p = 0.48).

6.3.1.2 Stimuli

This task used 60 black and white photographs from a standard set of pictures of facial affect (Ekman & Friesen, 1976). These comprised photos of 10 different individuals, each showing facial expressions of anger, happiness, sadness, fear, surprise and disgust.

6.3.1.3 Design and procedure

Participants viewed each photograph, presented on a computer screen, for as long as they liked, and selected the appropriate emotion from a list of six words adjacent to the photograph. The task was preceded by a short practice task containing six images, one of each of the six possible emotions. The individual in the practice images was different from those in the main task.

6.3.1.4 Data analysis

As in the animations task, for each emotion the scores across the two participant groups were compared using a Mann-Whitney non-parametric test. Again, Cohen's d was calculated from autism and control data for each of the six emotions, as a measure of effect size. The total scores across all emotions were also compared across the two participant groups. Finally, the data were used to create a confusion matrix of the responses made by the two groups to all six emotions, in an attempt to see which pairs of emotions were most commonly confused, and whether this differed in the autism and control groups.

6.3.2 Results

The autism group scored slightly lower than the control group in the recognition of all emotions apart from disgust, in which scores for the two groups were equal (table 9). The Mann-Whitney test revealed a significant difference between the autism and control groups for the sad faces (p = 0.018), but no difference for the other emotions (angry: p = 0.34; happy: p = 0.37; scared: p = 0.62; surprised: p = 0.77; disgusted: p = 0.70). There was also no significant difference between the two groups in the total

emotion recognition score (p = 0.286). Cohen's d revealed a large effect size of group for sadness recognition (d = 1.34), medium effect sizes for some other emotions (angry: d = 0.58, happy: d = 0.42, scared: d = 0.53), and little or no effect for surprise (d = 0.19) and disgust (d = 0). Figure 14 shows the mean scores for the two groups for all six emotions.

Group	Subject	Emotion recognition - animations				Living judgement - animations					Emotion recognition - faces			
		An	Ha	Sa	Sc	An	Ha	Sa	Sc	NL	An	Ha	Sa	Sc
Autism	1	3.0	0.5	3.5	-0.5	4.0	3.5	2.0	3.0	1	8	10	8	9
	2	3.0	1.5	1.0	1.0	2.5	3.5	2.5	2.0	1.5	10	10	8	8
	3	5.0	2.5	0.5	4.5	5.0	5.0	5.0	5.0	0.5	10	10	6	7
	4	0.0	2.5	0.0	3.0	4.0	5.0	3.0	4.5	4	8	9	4	0
	5	1.0	2.0	1.5	2.0	1.5	2.5	0.5	2.0	2	3	10	7	3
	6	4.0	5.0	3.0	5.0	4.0	4.0	3.0	5.0	2	6	10	6	7
	7	3.5	2.0	1.5	5.0	4.5	3.5	0.0	5.0	0	8	10	8	6
	8	1.5	5.0	0.5	1.0	5.0	5.0	0.0	4.0	1.5	8	10	8	10
	9	4.5	4.0	1.5	3.0	2.5	4.5	4.0	3.5	1.5	10	10	8	10
	10	4.0	-1.0	2.5	1.5	4.5	5.0	2.0	3.5	0	5	10	5	10
	11	1.0	0.0	0.5	3.0	4.0	3.5	0.0	3.0	5	6	10	6	1
	MEAN	2.77	2.18	1.45	2.59	3.77	4.09	2.00	3.68	1.73	7.45	9.91	6.73	6.45
	SE	0.50	0.58	0.34	0.54	0.34	0.26	0.52	0.34	0.47	0.68	0.09	0.43	1.09
NC	1	2.5	2.0	2.0	2.5	4.0	4.5	1.0	4.0	1	9	10	9	10
	2	5.0	2.5	2.5	3.5	2.0	4.5	4.0	4.5	2	10	10	10	6
	3	5.0	3.0	3.0	1.5	5.0	2.5	5.0	0.5	0	7	10	9	8
	4	5.0	4.0	3.5	1.0	3.0	5.0	0.0	5.0	1.5	8	10	7	8
	5	1.5	4.5	2.0	1.0	4.5	5.0	4.0	4.0	2	9	10	7	8
	6	5.0	5.0	3.5	3.0	0.0	4.5	2.5	4.5	0	8	10	10	6
	7	2.5	3.5	2.5	1.5	4.5	5.0	1.0	4.5	3	9	10	7	7
	8	-1.0	0.5	1.5	1.0	5.0	5.0	4.0	5.0	1.5	Did not complete task			
	9	1.5	2.5	1.5	2.0	3.0	4.0	1.5	3.5	2.5	8	10	9	9
	10	4.0	0.5	5.0	5.0	5.0	5.0	3.5	5.0	1	Did not complete task			
	11	5.0	2.5	3.5	5.0	4.0	5.0	5.0	5.0	0.5	9	10	9	10
	MEAN	3.27	2.77	2.77	2.45	3.64	4.55	2.86	4.14	1.36	8.44	10	8.44	7.89
	SE	0.61	0.44	0.31	0.46	0.47	0.23	0.53	0.39	0.29	0.33	0.00	0.46	0.38

Table 9. Scores for all participants. Emotion recognition scores are generated by subtracting the ratings for alternative emotions from those for actual emotions, and range from -5 to +5. A positive score indicates some ability to discriminate correctly between actual and alternative emotion labels. Living ratings of the animations range from 0 to 5. Emotion recognition scores from faces range from 0 to 10. (NC = normal controls, An = angry, Ha = happy, Sa = sad, Sc = scared, NL = non-living.)

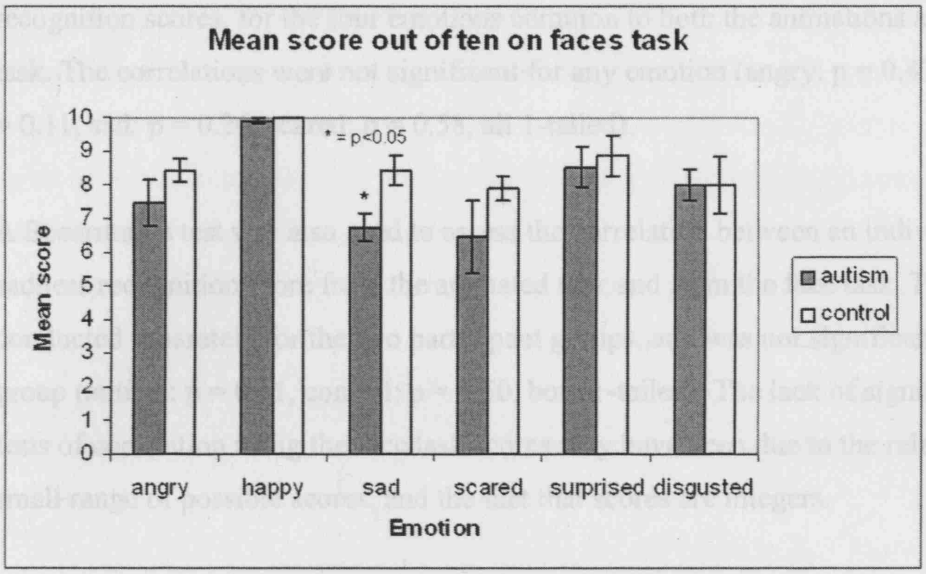

Figure 14. Mean scores for the autism and control groups on emotional faces task. The score indicates the number of faces that were assigned the correct emotion, out of the ten presented in each category. Error bars indicate standard error. * = $p<0.05$.

Table 10 shows a confusion matrix of the responses made by the two groups to all six emotions. Errors in both groups followed broadly the same pattern, though a cluster analysis revealed that participants with autism were more likely than controls to confuse sadness with fear, anger and disgust, and to confuse fear with anger.

	Stimulus					
Response	Angry	Happy	Sad	Scared	Surprised	Disgusted
Autism						
Angry	74.5	0	4.55	13.6	1.82	17.3
Happy	0	98.2	0	0.91	3.64	0
Sad	4.55	0.91	68.2	0	0	3.64
Scared	7.27	0	17.3	64.5	11.8	0.91
Surprised	0.91	0.91	1.82	15.5	82.7	0
Disgusted	12.7	0	8.18	5.45	0	78.2
Control	Angry	Happy	Sad	Scared	Surprised	Disgusted
Angry	84.4	0	1.11	3.33	0	18.9
Happy	0	100	0	0	0	0
Sad	1.11	0	86.7	1.11	0	1.11
Scared	4.44	0	8.89	78.9	11.1	0
Surprised	3.33	0	1.11	12.2	88.9	0
Disgusted	6.67	0	2.22	4.44	0	80

Table 10. Confusion matrix of the responses made to stimuli of each type by the autism and control groups. Figures indicate the percentage of responses that fell into each category.

As in the animations task, a Spearman's non-parametric test was used to assess the correlation between an individual's score on the RSI scale, and their emotion

recognition scores, for the four emotions common to both the animations and faces task. The correlations were not significant for any emotion (angry: $p = 0.47$, happy: $p = 0.11$, sad: $p = 0.26$, scared: $p = 0.58$, all 1-tailed).

A Spearman's test was also used to assess the correlation between an individual's sadness recognition score from the animated task and from the face task. This was conducted separately for the two participant groups, and was not significant for either group (autism: $p = 0.31$, control: $p = 0.50$, both 1-tailed). The lack of significance in tests of correlation using the face task scores may have been due to the relatively small range of possible scores, and the fact that scores are integers.

6.4 Discussion

The main finding of this study was a deficit in sadness recognition from both animations and photographs of faces, in the autism group. This effect was not simply due to the sadness task being more difficult: the scores of control participants do not suggest this was the case in either experiment (see **Figure 11b** and Figure 14). Indeed other studies have found sadness to be one of the emotions most easily recognised by normal individuals (Ekman & Friesen, 1978). That the sadness recognition deficit in autism was found in both experiments suggests that it is not specific either to facial expressions or motion cues.

First of all, however, it is necessary to consider alternative explanations for the apparent sadness recognition deficit indicated by the data, with particular regard to the animations task, as this is a novel measure. Poor performance on the task could occur for a number of reasons. Firstly, the task requires the processing of visual motion, which has been shown to be abnormal in individuals with autism (Milne et al, 2002; Spencer et al, 2000). Secondly, the task relies on holistic viewing of the animations to identify the emotions successfully, and there is evidence in autism of impaired global processing (Frith, 1989) or a bias towards local processing ("weak central coherence theory"; Happe, 1996). Finally, a failure to recognise the animated shapes as living would impair the attribution of the correct emotion to the triangle.

The scores on the 'living' task from Experiment 1 allow me to rule out these alternative explanations for the data. There was no significant difference between the two groups' perception of animacy in the animations in this task. This task has the same demands as the emotion recognition task in terms of motion processing, and in the holistic viewing of the animations. The fact that the participants with autism were able to perform this living task as well as controls suggests that poor performance on the sadness recognition task was not due to a general visual motion processing deficit, impaired global processing or a failure to recognise the shapes as living. It can therefore be concluded that low scores on the animated emotion recognition task in the autism group reflect a deficit in sadness recognition.

In addition, an interesting finding from the 'living' task is that both the autism and control groups were less inclined to rate the sad animations as living compared with the other emotions. The nature of the triangle's movement in this cartoon may have contributed to the relatively low living ratings for both participant groups.

It should be noted that this study found that the individuals with autism were impaired relative to the control group on the animations task, but that this does not mean that they retained no ability whatsoever to recognise sadness. Looking at the ratings for the sad animations in the autism group (Figure 11b), it can be seen that these were rated more highly on average for sadness than for the alternative emotion, showing some ability to recognise sadness in the animations. However, the lower sadness recognition scores for the autism group show that they did not show as great a difference between these two ratings as the control group did. I have interpreted this as arising from a lack of certainty or confidence amongst the autism group that the animations displayed sadness. However, it is possible that both groups were equally uncertain in their judgements, but that the control and autism groups differed in the way in which they used a rating scale under these conditions of uncertainty.

Animated tasks in autism research

The task used in this study is less verbally demanding than existing animated tests using abstract shape interactions (e.g. Klin, 2000; Castelli et al., 2000), making it more suitable for testing child clinical populations with language delay. Using abstract, unfamiliar stimuli avoids the potential confound of the use of compensatory

strategies by individuals with high-functioning autism, which might mask an underlying deficit for emotion recognition if familiar stimuli such as facial expressions are used (Teunisse & de Gelder, 2001).

Sadness recognition deficit in autism

A similar deficit in sadness recognition from facial expression has been reported in a recent study of adults with autism (Corden, Chilvers & Skuse, 2007), though it should be noted that this study included some of the same participants as the current study. Aside from this, there have been no previous reports of specific deficits in sadness recognition in the autism population. This could be partly due to a lack of power in individual studies due to the fact that most studies are based on small samples of autistic individuals, but also due to variability within the autistic population.

Despite a failure to find a sadness deficit in formal studies of individuals with autism, a frequent comment from parents of children with autism is that they fail to recognise when their parents are upset. The mother of one girl with autism commented that she (the mother), "broke down in tears in front of her and she didn't notice" (Skuse, D., personal communication). Deficits in recognising sad facial expressions tend to be associated with psychopathic traits (Blair, 1995; Stevens, Charman & Blair, 2001; Blair & Coles, 2000). Blair and Coles (2000) found in a study of normal adolescent children that problems recognising sadness and fear were associated with a higher level of affective-interpersonal disturbance in the form of callous or unemotional (CU) traits. Rogers et al. (2006) found that the recognition of sadness from faces was particularly impaired in boys with autism who also had high CU tendencies compared with boys with autism with low CU tendencies. Psychopathic traits were not measured specifically in the current study.

According to the various 'motivational/affective' accounts of face processing deficits in autism, these deficits arise from a lack of expertise with faces, as children with autism do not tend to 'seek out' faces in their environment (Grelotti, Gauthier & Schultz, 2002). It is possible that sadness recognition deficits could arise through a similar mechanism. A child could conceivably learn quickly that if another individual such as a parent was angry, this had particular consequences such as punishment. Learning to recognise signs of anger would therefore be advantageous. In contrast, the

sadness of a parent arguably does not reliably predict a particular action which affects the child, and is best understood purely in terms of the parent's mental state. For a child with autism, developing without an intrinsic interest in the social world (Dawson, Webb & McPartland, 2005), or in others' mental states, learning to recognise signs of sadness would not be a priority. It is conceivable that this early lack of interest could lead to a perceptual disadvantage that persists into adulthood, at which time social norms demand consideration of others' mental and emotional states.

There has been relatively little work on the neural correlates of sadness recognition. Blair et al. (1999) showed that viewing sad facial expressions activated the left amygdala and right temporal pole. Goldin et al. (2005) found that viewing sad films resulted in activations in a network of regions including the medial prefrontal cortex, superior temporal gyrus, precuneus, lingual gyrus and the amygdala. Wang et al. (2005) also found that the amygdala was activated by sad images, though a study by Killgore and Yurgulen-Todd (2004) failed to find amygdala activation. Goldin et al. (2005) found that viewing sad films activated a large number of brain areas including the medial prefrontal cortex and amygdala. A deficit in sadness recognition could therefore be explained by disrupted amygdala-cortical connectivity (Schultz, 2005).

Emotions other than sadness

In contrast to previous studies (Howard et al., 2000; Pelphrey et al., 2002), I did not find any significant deficit in fear recognition from facial expression in the autism group. On inspection of the data, this appears to be because although the difference between the group means is comparable to that for sadness, the variance in the autism group is much larger for fear than for sadness (Figure 14). This heterogeneity could explain why some studies have found a fear recognition deficit whilst others have not (e.g. Buitelaar et al., 1999; Castelli, 2005). Congruent with this trend in the forced choice data, the confusion matrix reveals that the autism group showed a slight tendency to confuse fear with anger and with sadness, compared with the control group.

I also found no deficit in fear recognition from abstract animations (**Figure 11**). In this task, scores were almost identical for the autism and control groups. This suggests that the fear recognition deficits found in previous studies might be specific to the

perceptual processing of faces, and therefore not extend to abstract stimuli. Results from eye-tracking studies with amygdala lesion patients (Adolphs et al., 2005) and adults with autism (Adolphs & Piven, personal communication; Dalton et al., 2005) suggest that specific deficits in fear recognition from facial expression could be caused by a failure to look at the eyes. This would not affect the perception of fear from animations (in which eyes are absent).

Given these documented abnormalities in eye-gaze patterns in autism (see the introductory chapter of this thesis for a fuller description), a potential extension of this study would involve combining the animated task with an eye-tracking paradigm. This would allow the investigation of whether abnormalities in gaze patterns in autism underlie emotion recognition deficits in autism a similar way to their involvement in the recognition of facial expressions of fear. In addition, given the previously unreported deficit in sadness recognition from faces found in this study, the use of eye tracking could identify whether this deficit, like reported fear-recognition deficits, arose from a failure to look at particular facial regions. The results could be interpreted in light of the findings of a recent study which identified the brow and mouth regions of the face as particularly important in the identification of sadness (Smith, Cottrell, Gosselin & Schyns, 2005).

This study showed no significant difference between the autism and control groups in the recognition of emotions other than sadness in either experiment. However, it is notable that the individuals with autism scored slightly lower than controls on the recognition of all emotions in the faces task (Figure 14), and all but one emotion in the animations task (**Figure 11b**), implying that this deficit may not be specific to sadness. In addition to large effect sizes for sadness, the values of Cohen's d obtained indicate moderate effect sizes for anger and happiness in both experiments, so testing with a larger sample might reveal significant differences for these other emotions. It should be noted that in the faces task, a ceiling-effect for happiness makes it difficult to determine whether the autism group was impaired in the recognition of this emotion.

Underlying neural mechanisms

I found parallel deficits in both experiments, despite the difference in nature of the

two tasks. This could be linked to the fact that both tasks involved 'social' stimuli, and it is possible that these parallel deficits could arise through the dysfunction of a single neural pathway. As discussed in the introduction to this thesis, and in the previous chapter, one brain region strongly implicated in the perception of social stimuli is the STS (Allison et al., 2000), and it is possible that abnormalities in the representation of certain stimuli in this region could lead to the deficits observed here. Abnormal processing in the STS region has been previously been implicated in the development of social perceptual deficits in autism (Zilbovicius et al., 2006), and grey matter abnormalities in this region are correlated with the degree of social impairment (Hadjikhani et al., 2006).

Reciprocal social interaction impairment and emotion recognition

As well as sadness recognition being significantly impaired for individuals with autism, there was a significant correlation between sadness recognition and reciprocal social interaction skills as assessed by the ADOS (Lord et al., 2000). This is the first study to demonstrate a correlation between a measure of emotion recognition and the severity of autistic symptoms. This fits with evidence that the level of social impairment in autism correlates with behavioural variables such as eye-gaze patterns (Klin et al., 2002b), and brain responses to socially salient stimuli (Dapretto et al., 2006).

Limitations

The design of the animated emotion recognition task presented some limitations for the assessment of an individual's ability to recognise that an animated triangle was living. This is because the emotion questions were only asked about the emotional animations, and not about the non-emotional non-living animations. Therefore, a participant could in theory deduce that an animation was living simply because he or she had previously been asked to judge the emotion in that animation. It is therefore possible that autistic individuals were in fact impaired on the living judgement and were simply using this strategy to compensate. This would indicate that their failure to interpret information from the animations was not specific to the judgement of emotion. However, feedback from the participants did not indicate that they were using this kind of strategy.

As discussed in chapter 4, animations for each emotion preceded a question about the intended emotion, and questions about two alternative emotions. As not all possible emotion confusion pairings were tested, this means that a deficit apparently selective for a particular emotion could arise simply because this animation appeared with more easily confused alternative emotions. The sad animations appeared with two alternative options: scared after one presentation, and angry after another. A tendency to confuse sadness with fear could not erroneously lead to an apparent sadness recognition deficit, as the scared animations included sadness as an alternative option, and there was no deficit in the recognition of the scared animations. However, a tendency to confuse sadness with anger could have been behind the apparent deficit in recognition of sadness from the animations. Given the parallel sadness recognition deficit found from the face stimuli, however, this explanation is unlikely.

Related to this potential caveat is the fact that, for the animated task, the emotion recognition score for each of the four emotions was based on the viewing of only two animations, with each animation being presented twice. The small number of animations means that only limited generalisations can be drawn to other stimuli. However, the simplicity of the stimuli meant that there was only a limited number of different ways in which a single emotion could be conveyed in a short animation. In terms of the small number of trials, the test-retest data presented in chapter 4 of this thesis indicate that the test is a reliable measure, therefore one would expect scores to be consistent were a larger number of repetitions to be included.

A further limitation should be considered when drawing conclusions from the data presented in this chapter. The impression of emotion elicited by the animated stimuli depends on the perception of interaction between the two shapes. An apparent deficit in emotion recognition could therefore arise from a failure to identify interactions between the shapes. However, given that the autism group in this study was unimpaired in the recognition of at least some of the emotions from the animations, this factor is unlikely to underlie the sadness recognition deficit identified in this study.

Conclusion

I found evidence for impaired sadness recognition in autism, using tasks that relied on

two quite different cues – facial expressions and movement patterns. Given the evidence that similar brain areas, such as the STS, are activated by both images of faces, and abstract animated stimuli, abnormal functioning of these areas could plausibly lead to a deficit in emotion recognition of this type. A more extensive investigation, using brain imaging, is needed in order to test this.

In the study described in the next and final experimental chapter of this thesis, I further investigate the social perceptual abilities of high-functioning adults with autism. Once again, I consider the importance of acquired expertise in the performance of social tasks, but this time using naturalistic rather than abstract stimuli (human faces). Again, I develop a task which is designed to avoid the ceiling effects common in emotion recognition tasks.

Chapter 7 Perception of genuine and posed smiles by individuals with autism

7.1 Introduction

In the previous chapter, I found a deficit in sadness recognition in adults with autism, and hypothesised that this could be due to a lack of expertise specific to sadness cues, caused by diminished social interest early in development. In this chapter, I aim to further investigate the importance of perceptual expertise in emotion recognition, returning once more to the processing of facial cues.

As addressed in the introductory chapter of this thesis, abnormalities in the processing of faces are well documented in autism. These processing differences translate into performance deficits on face-related tasks, one of which is the impaired recognition of facial expressions of emotion, in particular fear (Howard et al., 2000; Pelphrey et al., 2002).

It has been suggested that difficulties are more pronounced for fear recognition because the identification of fear relies more heavily on the eyes than other emotions (Adolphs et al., 2005). Individuals with autism do not look at the eye region as often as normal controls when viewing images of faces (Pelphrey et al., 2002; Dalton et al., 2005; Dalton, Nacewicz, Alexander, & Davidson, 2007) or video clips of social scenes (Klin et al., 2002b). Taken together, these findings suggest that poor performance of individuals with autism on tasks of face perception, such as recognising a fearful facial expression, might be linked to a reduced tendency to look at the eyes.

In this current study I aimed to investigate another potential perceptual and social consequence of reduced eye fixation. In addition to fearful faces, the eye region is also important when identifying genuine, or sincere, smiles. In 1862 the French neurologist, Duchenne de Boulogne, showed that the critical factor in distinguishing a posed from a genuine smile is contraction of the *orbicularis oculi* muscle which surrounds the eye. Genuine (or "Duchenne") smiles are accompanied by contraction

of these muscles, causing wrinkles of the skin in the outer corners of the eyes, known as 'crow's feet' wrinkles (Hager & Ekman, 1985; Ekman, 1989). In a study of the imitation of facial expressions by children, Ekman and colleagues (Ekman, Roper & Hager, 1980) showed that the outer part of the *orbicularis oculi* muscle, the pars lateralis, which causes the crow's feet wrinkles, is not under voluntary control, and therefore this region can not contract in a posed smile. There is evidence that people make more and longer fixations to the crow's feet region of happy faces than of sad or neutral faces, and thus it has been suggested that happy faces are automatically checked for the presence of the crow's feet marker (Williams, Senior, David, Loughland, & Gordon, 2001). Certainly, the presence of a Duchenne smile appears to impact on certain aspects of social cognition – individuals displaying Duchenne smiles are rated by observers as more 'positive' (expressive, natural, outgoing, sociable, relaxed, and pleasant) than those displaying non-Duchenne smiles, even when the observers are not explicitly asked to focus on the smile (Frank, Ekman & Friesen, 1993).

In this study I investigated the ability of adults with autism to distinguish genuine and posed smiles. At the same time, gaze behaviour in relation to the eye region and, for comparison, the mouth region of the face was monitored using an eye-tracker. I hypothesised that individuals with autism would, firstly, be impaired at discriminating genuine and posed smiles, and secondly, show a reduced tendency to look at the eye region of the face when making judgements about smiles. Furthermore, I investigated whether the ability to discriminate genuine and posed smiles was associated with social interaction impairment as measured by the reciprocal social interaction score of the ADOS (Lord et al., 2000) in the autism group[2].

7.2 Methods

7.2.1 Participants

I tested 18 individuals with autism (15 males) and 18 control subjects (15 males), matched for age. The groups were matched for verbal and performance IQ, as

[2] Some of the results presented in this chapter have recently been published in a research article (Boraston, Corden, Miles, Skuse & Blakemore, 2007).

measured by the Wechsler Abbreviated Scale of Intelligence (WASI). Full details of the groups are given in Table 11.

All participants in the autism group had a diagnosis of autism, Asperger syndrome or autism spectrum disorder from a GP or psychiatrist. The diagnosis was confirmed by administering the Autism Diagnostic Observation Schedule (ADOS) (Lord et al., 2000). In total, 10 participants met the criteria for autism, and the remaining 8 for autism spectrum disorder. All participants were screened for exclusion criteria (dyslexia, epilepsy, and any other neurological or psychiatric conditions) by self-report prior to taking part in the study. All participants gave informed consent to take part in the study, which was approved by the local ethics committee.

7.2.2 Stimuli

Stimuli were colour photographs taken from a set of male and female faces. Three photographs of each individual were used: a neutral facial expression, a genuine smile and a posed smile. In the current study, photographs of 10 female faces were used. Six of these were from a set used in previous studies (Miles & Johnston, 2006; Peace, Miles & Johnson 2006), in which a full description of their creation is given, and the remaining four were created at a later date using the same procedure. This procedure involved filming a set of volunteers whilst asking them to watch and listen to a variety of stimuli, and perform certain tasks. Volunteers were unaware of the purpose of this procedure, and did not know that the study was concerned with research into smiles or facial expressions. Stills from the video recording were then used to create the photographs. For the neutral shots, volunteers were asked to present a neutral expression to the camera. For the posed smiles, they were asked to pose a smile as they would for having a passport photograph taken, or for having a family portrait taken. Following this, volunteers listened to a piece of music designed to induce a positive mood. The volunteers then listened to a series of short audio clips and viewed a series of photographs designed to elicit spontaneous smiles of enjoyment. The frames of the videotape of this section were then examined to isolate enjoyment smiles. The criteria for a genuine smile comprised the contraction of the orbicularis oculi muscle creating visible 'crows feet' wrinkles, and the subjective experience of positive mood in the volunteer. For the purpose of this study, the photographs from this set were close-cropped to show only the face (see figure 15).

7.2.3 Design and procedure

This experiment comprised two conditions. In the **Smiles** condition, participants were presented with a total of 60 faces: each of the 10 individuals in the stimulus set was shown three times with a genuine smile and three times with a posed smile. Participants were asked to make a decision about whether the smile in each photograph was real or posed. This task was described in detail – participants were provided with a written description of the task, and the task was then explained verbally by the experimenter. A variety of terms were used to explain the concept of a posed smile to the participant ('posed', 'fake' and 'false', versus 'real' and 'genuine') and the experimenter checked that participants understood what was meant by the task. No participant reported any difficulty in understanding the nature of the task.

Figure 15. Sample images of a genuine smile (left), and a posed smile (right) from the stimulus set. Gaze points that fell within the boxes were used to calculate gaze time to the eye region or the mouth region.

In the **Control** condition, participants again saw 60 faces: each individual in the stimulus set was shown three times with a smiling expression and three times with a neutral expression. Half of the smiling pictures in the control task were taken from the genuine smile set, and the other half from the posed set. Participants were asked whether the facial expression in each photograph was smiling or neutral. This control

task was chosen because it involved making judgements about the same set of faces as in the Smiles condition.

The order of presentation of the faces in both conditions was random, and the order in which the Smiles and Control conditions occurred was counterbalanced across participants.

Participants viewed each face on a computer monitor at a distance of approximately 800mm. The faces were scaled to the full height of the computer monitor, subtending approximately 17 degrees of visual angle. Faces were displayed for 2.5 seconds each, preceded by a central fixation cross of duration 1.5 seconds. Participants were instructed to look directly at the fixation cross while it was on the screen. In both conditions, after each face had disappeared, participants were required to make a response. Participants pressed one of two keys, corresponding to the labels 'real' and 'posed' (Smile condition), or 'smiling' and 'neutral' (Control condition), which appeared on the computer screen. Prior to the experiment participants practised the task with a different set of faces, taken from the same set of stimuli as those used in the main part of the experiment.

7.2.4 Collection of eye-tracking data

During the task, participants' eye movements were recorded using an ASL6000 series remote eyetracker, in conjunction with a video head tracker. The position of the participant's pupil and corneal reflection were recorded at a rate of 50Hz, and used to calculate the coordinates of the participant's point of regard on the screen. To maintain the accuracy of this calculation, the eyetracker was calibrated before each condition by asking the participant to look at 9 predefined points on the screen. To allow for disruptions to this calibration caused by head movements, eye position was also recorded during the display of the central fixation cross prior to each trial. Any offset of the point of regard from the fixation cross was applied to correct the data collected on the subsequent trial.

Data from each trial comprised 125 coordinate pairs, detailing the position of the eye every 20ms. First, measurements corresponding to points of regard outside the computer monitor were removed. For each face, the eye region was defined prior to

data collection, by drawing a rectangular box around each eye, to include the entire eye, plus the region lateral to the eye in which 'crows feet' wrinkles would be found in a genuine smile. The percentage of time for which participants looked at the mouth region was calculated in the same way, by drawing a rectangular box around the mouth. Examples of these boxes are shown in figure 15. For each individual in the photographs, boxes were the same size in the genuine smile photograph and the posed smile photograph.

Two measures of gaze behaviour were calculated: (a) Gaze time. Data from each trial were analysed to determine how many of the gaze coordinate pairs fell within the eye region of the face, indicating the percentage of the display time for which the point of regard was within this region. The same calculation was performed for the mouth region. (b) Fixations. Data from each trial were analysed to compute the number of fixations the participant made during the trial. A fixation was assumed if the eye remained within 1 degree of visual angle for at least 100ms. The coordinates of every fixation made were recorded for each trial. The fixation points for each trial were then analysed to determine how many were to the eye region and to the mouth region of the face.

7.2.5 Data analysis

For both the Smiles condition and the Control condition, scores from the two participant groups were compared using a univariate ANOVA with verbal IQ as a covariate. For the Smiles condition I measured 1-tailed significance, as my *a priori* hypothesis was that any difference between the two groups would arise from a deficit in performance in the autism group. The two measures of gaze behaviour (gaze time and fixations) were each analysed using a mixed design repeated measures 2x2 ANOVA with the factors group (autism vs control) and facial region (eye vs mouth), using verbal IQ as a covariate. Post-hoc simple-effects analyses were performed on individual contrasts for both of these measures. In order to investigate the effect of fixation behaviour on performance of the Smiles task, the univariate ANOVA on the behavioural scores on this task was repeated, but this time including percentage of fixations made to the eye region as a covariate. Throughout the analysis verbal IQ was used as the covariate rather than full-scale IQ given the large discrepancy between

verbal and performance scores for some participants with autism which prevented a meaningful estimation of full-scale IQ.

7.3 Results

7.3.1 Behavioural data

For both the Smiles and Control conditions, the number of faces correctly identified out of a possible 60 was totalled for each participant. For the Smiles condition, the mean score out of 60 was 37.6 for the autism group and 42 for the control group. Each individual participant scored at or above 50% for this task, but when the binomial distribution was used to investigate which participants scored significantly above chance, only 10/18 of the autism participants and 16/18 of the control participants met this criterion.

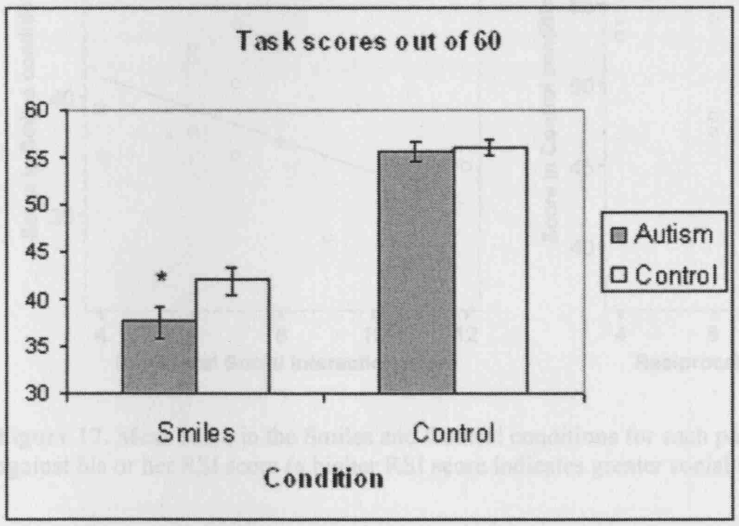

Figure 16. Mean scores of the autism group and the control group in the Smiles condition (discriminating a genuine from a posed smile), and in the Control condition (discriminating a happy from a neutral face). Participants with autism scored lower than controls in the Smiles condition ($p = 0.035$, 1-tailed). Error bars indicate standard error.

A univariate ANOVA using verbal IQ as a covariate revealed that the autism group scored significantly lower than the control group in the Smiles condition ($F_{(1,33)} = 3.537$, $p = 0.035$, 1-tailed). In contrast, scores in the Control condition were not significantly different between the two groups ($F_{(1,35)} = 0.872$, $p = 0.357$), see Figure 16. On both tasks, scores were similar for participants with autism and those with autism spectrum disorder (mean smiles task scores: 36.7 for autism participants, 38.8

for autism spectrum participants; mean control task scores: 57.0 for autism, 53.9 for autism spectrum).

7.3.2 Correlation between task performance and autism symptoms

For the participants with autism, I correlated performance in the Smiles condition with the participants' social interaction skills as assessed by the reciprocal social interaction (RSI) measure of the ADOS (Figure 17). A Pearson test revealed a significant negative correlation between each participant's score on the RSI scale, and his or her score in the Smiles condition ($R = -0.469$, $p = 0.049$). As a comparison, I assessed the correlation between the RSI scores and the score in the Control condition. This correlation was not significant ($R = 0.087$, $p = 0.732$).

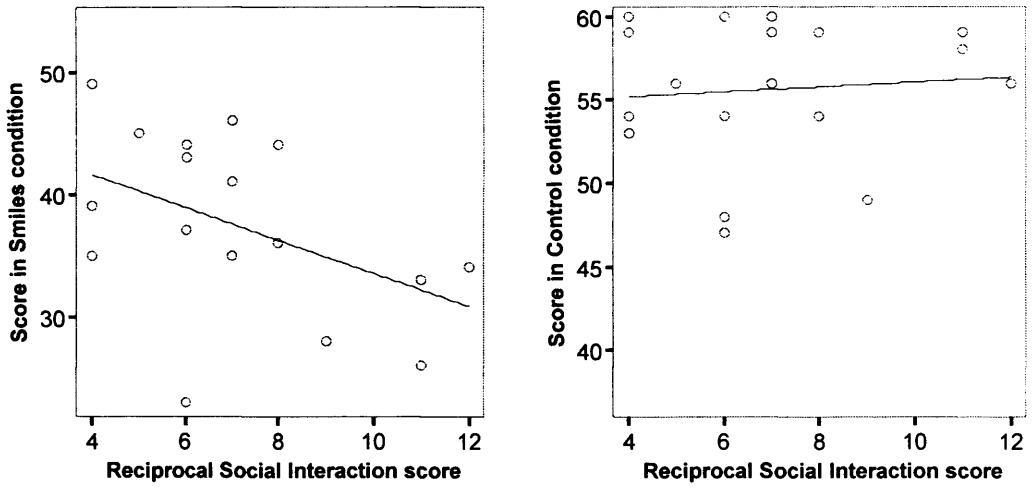

Figure 17. Mean score in the Smiles and Control conditions for each participant with autism plotted against his or her RSI score (a higher RSI score indicates greater social impairment.

7.3.3 Eye-tracking data from the autism and control groups

For technical reasons, eye-tracking data were only available from a subset of these participants: 11 adults with autism and 11 control adults. Full details of the groups are given in Table 11.

7.3.3.1 Gaze time

When looking at the percentage of gaze time spent looking at the eyes or the mouth, there was no significant main effect of facial region ($F_{(1,19)} = 2.113$, $p = 0.162$) or participant group ($F_{(1,19)} = 0.865$, $p = 0.364$). However, there was a significant interaction between group and facial region ($F_{(1,19)} = 8.071$, $p = 0.010$). An analysis of

simple effects revealed that this was driven primarily by the autism group spending significantly less time than the control group looking at the eye region ($p = 0.033$, Figure 18). There was a trend towards individuals with autism looking more than controls at the mouth region ($p = 0.065$).

	Behavioural experiment			**Eye-tracking experiment**		
	Autism group	Control group	Group comparison	Autism group	Control group	Group comparison
N	18	18		11	11	
Gender (M:F)	15:3	15:3		9:2	8:3	
Age in years	35.4 (±12.3)	36.7 (±14.0)	$t_{(34)} = 0.316$ $p = 0.754$, ns	34.6 (±9.01)	39.6 (±11.1)	$t_{(20)} = 0.319$ $p = 0.753$, ns
Verbal IQ	117 (±11)	112 (±11)	$t_{(34)} = 1.215$ $p = 0.233$, ns	118 (±11)	111 (±12)	$t_{(20)} = 1.412$ $p = 0.173$, ns
Performance IQ	119 (±15)	114 (±11)	$t_{(34)} = 1.165$ $p = 0.252$, ns	120 (±9)	113 (±9)	$t_{(20)} = 1.718$ $p = 0.101$, ns

Table 11. Details of participants included in the analysis of data from the behavioural and eye-tracking components of the study (ns = not significant).

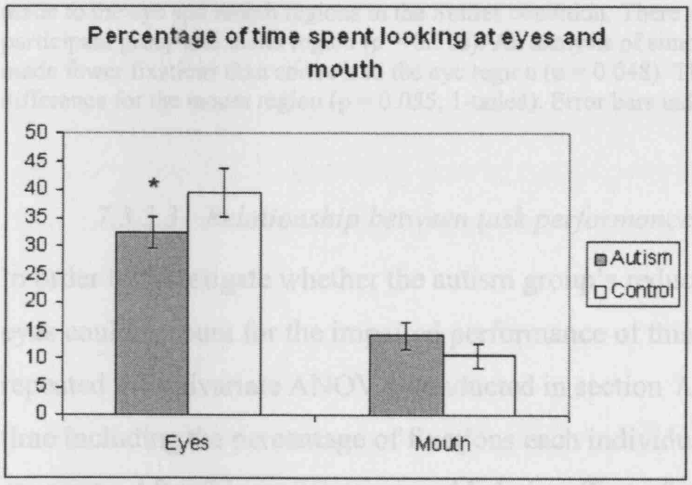

Figure 18. Eye-gaze data from the autism and control groups, showing the percentage of gaze time within the eye and mouth regions in the Smiles condition. There was a significant interaction between participant group and facial region ($p = 0.010$). An analysis of simple effects showed the autism group spent less time than controls looking at the eye region ($p = 0.033$). The difference for the mouth region approached significance ($p = 0.065$). Error bars indicate standard error.

7.3.3.2 Fixations

For the autism and control groups, I looked at the percentage of fixations that were made to the eyes, or the mouth. A 2x2 ANOVA showed no significant main effect of facial region ($F_{(1,19)} = 1.302$, $p = 0.268$) or participant group ($F_{(1,19)} = 0.922$, $p = 0.349$). However, there was a significant interaction between region and participant group ($F_{(1,19)} = 6.920$, $p = 0.016$). Simple effects analysis demonstrated that the interaction was driven by the autism group making significantly fewer fixations than

the control group to the eye region (p = 0.048, Figure 19). There was also a trend towards individuals with autism making more fixations than the controls to the mouth (if an a priori direction of difference is assumed: p = 0.055, 1-tailed).

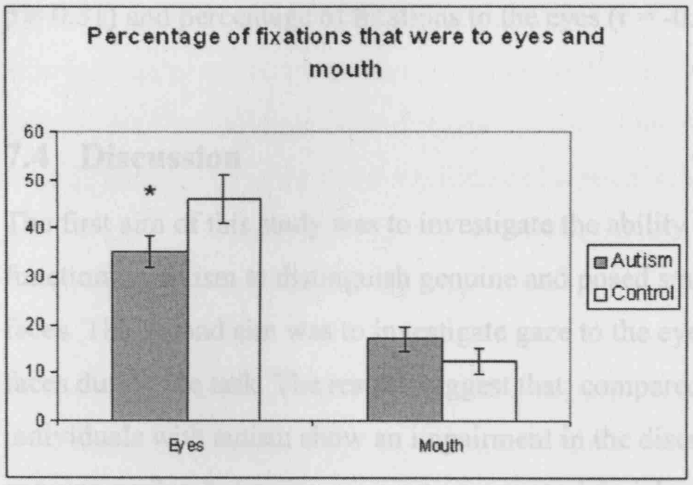

Figure 19. Eye-gaze data from the autism and control groups, showing the percentage of fixations made to the eye and mouth regions in the Smiles condition. There was a significant interaction between participant group and facial region (p = 0.016). An analysis of simple effects showed the autism group made fewer fixations than controls to the eye region (p = 0.048). There was a trend towards a difference for the mouth region (p = 0.055, 1-tailed). Error bars indicate standard error.

7.3.3.3 Relationship between task performance and gaze behaviour

In order to investigate whether the autism group's reduced tendency to look at the eyes could account for the impaired performance of this group on the Smiles task, I repeated the univariate ANOVA conducted in section 7.3.1 of this chapter, but this time including the percentage of fixations each individual made to the eyes as a covariate. After this covariate was added, the effect of subject group was no longer significant (F = 1.235, p = 0.282), suggesting that the reason for the diminished performance of the autism group was indeed their reduced fixation of the eyes.

In addition, for both participant groups, I correlated performance in the Smiles condition with the percentage of gaze time spent looking at the eye region, and the percentage of fixations that were to the eye region. A Pearson test revealed that none of these correlations was significant, for the autism group (with gaze time: r = 0.21, p = 0.54; with fixations: r = 0.33, p = 0.32) or for the control group (with gaze time: r = -0.25, p = 0.49; with fixations: r = -0.21, p = 0.56).

As a previous study on individuals with autism has found a relationship between gaze behaviour and social competence (Klin et al., 2002b), I assessed the correlation between gaze behaviour and RSI impairment within the autism group. The results of these correlations were non-significant, both for total gaze time to the eyes ($r = -0.34$, $p = 0.31$) and percentage of fixations to the eyes ($r = -0.44$, $p = 0.17$).

7.4 Discussion

The first aim of this study was to investigate the ability of adults with high functioning autism to distinguish genuine and posed smiles from photographs of faces. The second aim was to investigate gaze to the eye and mouth regions of the faces during the task. The results suggest that, compared with matched controls, individuals with autism show an impairment in the discrimination of posed from genuine smiles, but no impairment on a control facial expression discrimination task (Figure 16). In addition, I found that the ability to discriminate genuine and posed smiles was inversely related to the degree of social interaction impairment in the autism group (Figure 17). Finally, the results demonstrated a different gaze and fixation pattern in the autism and control groups, with individuals with autism looking significantly less at the eye region compared to the control group (Figure 18 and Figure 19).

Posed smile recognition deficit in autism

I have interpreted the behavioural results of this study as indicating a selective impairment in the recognition of posed smiles. However, it is important to consider alternative interpretations of the data. First, ceiling effects in the control task might have obscured significant group differences in the performance of this task. It proved difficult to find an ideal control task, as I wanted a task which was still social-perceptual in nature, but which did not require attention to the eyes. Second, poor performance of the autism group in the Smiles task might be due to a less specific social cognitive impairment, such as in the processing of subtle social information in general. Alternatively, the apparent deficit may have been due to general difficulties with fine perceptual discrimination, as the differences between faces in this task may have been more subtle perceptually than between faces in the control task.

The concept of a posed smile relies on the understanding that the individual smiling has the intention to deceive, or give an impression which is at odds with their actual emotional state. This requires the use of Theory of Mind (ToM), the understanding that other individuals have unobservable mental states which drive their behaviour. Given the evidence for ToM deficits in autism, it was necessary to ensure that a failure in the posed smile task was not due a deficit of this type which could make it difficult for the individual to understand the task. Pains were therefore taken to ensure that all participants understood the nature of a posed smile. No participants reported any difficulty with this, and this could have been due to the fact that the autism group comprised only high-functioning individuals.

Assuming that the observed deficit was specific to the discrimination of posed smiles, there are many ways in which such a deficit might arise. One factor could be the strategy that individuals with autism use to recognise facial expressions. A rule-bound approach, perhaps explicitly learned, such as looking for upturned corners of the mouth to identify happiness, would aid performance in the control task of this study, but a rule for identifying a posed smile is less likely to have been explicitly taught, thus an individual with autism who adopted a rule-bound approach would have difficulty with unusual or subtle face-perception tasks such as the Smiles task.

Eye-tracking can offer an insight into the strategies an individual is using to perform a visual perceptual task, and a compelling interpretation of these behavioural results is that they are linked to the differences in gaze patterns that were observed during eye-tracking. This possibility is explored further in the subsequent section of this discussion.

Interpretation of eye-tracking results

The eye region is known to convey information about whether a smile is genuine or posed (Hager & Ekman, 1985; Williams, Senior et al., 2001). The eye-tracking data show a reduced tendency of the autism group to look at the eyes of the photographs, suggest that this might explain their impaired performance on this task. The fact that the inclusion of fixation behaviour as a covariate removed the effect of subject group on Smiles task performance supports this explanation.

Despite this evidence that fixation behaviour was the underlying reason behind the difference between the two groups in their scores on the Smiles task, the correlation analysis did not reveal a relationship between these variables at the level of individual participants. This could be explained by the idea that the relationship between gaze to eyes and task performance is not an immediate one, but is developmental in nature. It is conceivable that it is an individual's tendency to look at eyes in general, rather than on a specific occasion, that is important. It is this which allows the development of expertise in using the cues present in the eye region. An individual with autism might thus know the eye region to be important in identifying a posed smile and look more at this region during the task, but a lack of experience with the eye region and consequent lack of expertise could prevent good performance on the task.

Current theories concerning the origin of face-processing deficits in autism might be relevant to the interpretation of these results. The introduction to this thesis describes evidence supporting the idea that faces are processed differently in autism. It has been proposed that the various explanations put forward to explain these differences can be divided into two classes (Dawson, Webb & McPartland, 2005). Perceptual/cognitive accounts hold that the fundamental deficit is a general problem with perception, or higher-order cognition, that prevents normal processing of faces in autism. Theories that invoke a fundamental dysfunction of the fusiform face area in autism also fall into this category. These explanations allow for the fact that wider social cognitive deficits might occur as a result of the primary perceptual or cognitive dysfunction. In contrast, in motivational/affective explanations, the primary deficit is in the motivation to seek out social stimuli in autism (e.g. Dawson et al., 2002; Grelotti et al., 2002). This leads to a reduced exposure to faces, especially in the context of meaningful social interactions. The importance of early exposure to social stimuli and its impact on the later development of cortical circuitry for face processing of these stimuli has long been recognised (Morton & Johnson, 1991), and according to motivational/affective accounts, a lack of such exposure in autism leads to a lack of expertise with faces, and a failure to develop normal face-processing mechanisms.

This effect of diminished social interest, highlighted in motivational/affective explanations, has been used to account for a number of observed differences in face processing in autism. One example of this is in a recent study using an adaptation

paradigm (Pellicano, Jeffery, Burr & Rhodes, 2007). In this study, participants had to perform an identity discrimination task on faces which were artificially morphed to vary along a continuum between two individuals. Control children showed an adaptation aftereffect, in which prior exposure to a face of particular identity biased their subsequent responses. This was interpreted as evidence that facial identity is coded relative to a perceptual 'norm', which can be shifted by prolonged exposure to a particular face. Children with autism spectrum disorder showed a much reduced adaptation effect, which was interpreted as evidence of abnormal face-coding mechanisms. Pellicano and colleagues suggest that these abnormal mechanisms could have arisen through diminished social interest early in life. The results of the current study suggest that this impact of social interest on the development of representations of faces might extend to other aspects of social perception, such as interpreting social cues from the eyes. Given that eye-contact is an important component of everyday social interaction, a lack of social interest in autism could result in reduced exposure to eye-contact, and a consequent lack of expertise in interpreting cues from the eye region. This would impact upon any task which required interpretation of these cues, including the identification of a posed smile.

A number of studies have investigated the ability of individuals with autism to use information from the eye region, and several studies have found evidence of impairment (Baron-Cohen, Wheelwright & Joliffe, 1997; Baron-Cohen, Joliffe, Mortimore & Robertson, 1997; Baron-Cohen, Wheelright, Hill, Raste & Plumb, 2001; Spezio et al., 2007a). However, a recent study of children with autism found that they were in fact able to use information from the eyes: when this information was available, the children scored more highly than when it was not (Back, Ropar & Mitchell, 2007). These aforementioned studies have been concerned with the recognition both of basic emotions (Spezio et al., 2007a), and more subtle mental states (e.g. Baron-Cohen et al., 1997; Back et al., 2007). No studies so far have looked specifically at the use of information from the eyes for identifying posed smiles.

The 'expertise' explanation of the data from this study makes the prediction that an individual's gaze patterns in the absence of any task would be more indicative of his or her tendency to look at the eyes in general, and would thus be a better predictor of his or her performance on this task. This could potentially be tested in future studies.

In addition to the differences in gaze and fixation to the eyes, I also found a trend towards increased fixation of the mouth region in the autism group, but the differences between the groups are not as clear as for the eyes, perhaps due to greater variability in mouth fixation behaviour in the autistic population. This variability might explain the inconsistent results of previous studies: some studies have reported increased fixation of the mouth in autism (Klin et al., 2002b; Spezio et al., 2007a), others have found reduced fixation (Pelphrey et al., 2002) and others no difference (Dalton et al., 2005).

Reciprocal social interaction impairment and task performance

As discussed in chapter 6, it has been proposed that social information processing, including the interpretation of facial expressions, is linked to social interaction deficits in autism (Joseph & Tager-Flusberg, 2004). For this reason, I evaluated the correlation between an autistic participant's score on the test, and his or her degree of reciprocal social interaction (RSI) impairment. Indeed, the results showed that those individuals who were most impaired in the recognition of genuine smiles had more deficits in the RSI domain (Figure 17). The ability to distinguish a real from a posed smile has an obvious significance in everyday social interaction, as it is linked to the understanding of another's mental state, perhaps even a higher-order mental state, as a posed smile can indicate the pretence of happiness or pleasure. Failure to identify these subtle facial cues could conceivably lead to difficulties in social interaction – for example, impaired judgement in social situations, or an inability to 'take the hint' or 'read between the lines,' similar to reported deficits in the interpretation of non-literal language, including irony, in autism (Happe, 1993; Martin & McDonald, 2004).

Unlike Klin et al. (2002b), I found no direct correlation within the autism group between an individual's gaze behaviour group and his or her degree of RSI impairment. This is in line with the idea that reduced gaze to the eye region impacts on social interaction ability only in an indirect way, via reduced exposure to the eyes and a consequent lack of expertise in interpreting cues from this region.

Future directions

A valuable extension to the work described in this chapter could involve further investigation of the regions of these photographs which are essential for the

completion of the task. As discussed in the introduction to this chapter, previous research has identified the eye region as essential for the discrimination of genuine from posed smiles. However, this could have been confirmed with the current stimuli prior to the completion of the study, by investigating the performance of control participants on the Smiles task, using photographs in which the eye region had been obscured, or in which only the eye region was visible, to confirm that the eye region of these stimuli was necessary and sufficient to perform the Smiles task. It would also have been interesting to investigate the perception of these partially occluded stimuli by the autism group. If it is the reduced tendency to look at the eyes which underlies the poorer performance of the autism group on the Smiles task, one would predict that the autism and control groups were perform similarly when using photographs with the eyes occluded.

Sensitive measures of face-processing such as this task could be useful in the testing of relatives of autistic individuals who are often described as fitting a 'broad autism phenotype' (BAP) - a mild predisposition towards autistic traits, which when combined with environmental influences might develop into autism in some cases (for a review see Piven, 2001). A recent study has shown that relatives of individuals with autism show unusual gaze patterns when viewing faces (Dalton, Nacewicz, Alexander, & Davidson, 2007), indicating that abnormal fixation patterns might form part of this BAP. An extension to the current study would be to investigate performance on this task in relatives of autistic individuals, to see if this particular impairment present in autism could form part of the BAP.

Summary

In summary, the results of this study demonstrated an impaired ability in the autism group to discriminate genuine from posed smiles. Second, I found that individuals who were most impaired in the recognition of genuine smiles had more severe social interaction deficits. Finally, I found that the autism group showed reduced fixation of the eye region. I suggest that this reduced fixation to the eyes could account for the problems discriminating genuine from posed smiles in the autism group.

Chapter 8 General discussion

8.1 Summary of findings

In the studies described in this thesis, I used a variety of approaches and techniques to address the same question: how does the neural architecture of the human brain enable the instant, seemingly effortless recognition of emotion that most of us are capable of?

I started by investigating what is undoubtedly the most-studied cue to emotion – the facial expression. In this study I adopted a relatively novel experimental technique – the analysis of fMRI data using pattern classification. The aim of this study was to investigate where the identity of an emotional expression might be represented within the brain, by probing two candidate areas: the amygdala, and the fusiform cortex.

The results did not provide sufficient evidence in favour of a representation of emotional identity in either of these areas. From this I concluded that either the identity of individual emotions is represented elsewhere in the brain, or the representation in the brain regions I investigated is encoded at too fine a spatial scale to be detected by current neuroimaging techniques.

I then conducted three related studies designed to investigate how the architecture of the 'social brain' enables emotion recognition from other cues available in the sensory environment. I hypothesised that social movement patterns, even in the absence of other cues, would be sufficient to allow accurate recognition of emotion. A large-scale study using abstract computerised animations confirmed this hypothesis.

In the second of these three studies I used fMRI to identify the brain regions involved in emotion recognition from these social movement cues. I found that the brain regions activated by emotional stimuli depended to some extent on the modality of the stimuli, but that an emotion recognition task elicited activation of regions of the inferior frontal gyrus (IFG) in all three modalities tested – faces, voices and abstract animations. Brain regions particularly involved in the processing of emotion from animations included movement-sensitive regions in the posterior temporal and

superior parietal lobes. This study also confirmed the involvement of the STS and adjacent cortices in the processing of emotional stimuli.

In the third such study I investigated how a selective social cognitive impairment, as present in individuals with high-functioning autism, might affect the recognition of emotion from these social movement cues. I found that adults with autism showed a deficit in sadness recognition from movement cues and, unexpectedly, this deficit extended to the recognition of sadness from facial expressions. I hypothesised that a general deficit in sadness recognition could arise from a lack of expertise with this emotion in particular, brought about by a lack of interest in the mental states of others.

In the final study described in this thesis I further investigated the impact of early-acquired expertise on emotion recognition ability, again in adults with autism. I found that these adults were impaired in their discrimination of genuine from posed smiles. Using eye-tracking data collected during testing, I showed that these adults looked at the eyes less often than control adults. I concluded that this reduced tendency to look at the eyes was behind the poor performance on this particular facial emotion task. In both studies on the autistic group, I found that an individual's performance on the task correlated with his or her social interaction ability, as assessed by the ADOS.

8.2 Implications of findings, and further discussion

In this thesis I investigated how the brain is set up to enable the recognition of emotion: from facial expressions and from social movement cues. I also looked at how social interaction deficits impact on emotion recognition ability. I will now discuss these two issues in more detail, before moving on to consider possible neurobiological explanations of emotion recognition deficits, and how the study of those with such deficits can extend our knowledge of the brain basis of emotion recognition.

8.2.1 The brain basis of emotion recognition

In the introduction to this thesis I described the brain regions that have been implicated in emotion processing, and discussed the evidence for their involvement in

the recognition of emotion. Although a number of important regions have been identified, this branch of social neuroscience is at an early stage, and there is at present no clear model of how these areas might interact in the emotion recognition process. There are a number of ways in which functional imaging can be employed to investigate this.

First, studies in which the participant's task is manipulated experimentally (as in chapter 5) can indicate which brain regions are influenced by paying attention to emotion, and are thus likely to be subject to top-down influences rather than being purely stimulus-driven in their processing. A second useful approach is to investigate what information is actually represented in the pattern of neural activity in a particular region. This is the motivation behind decoding-based studies, in which the fMRI data are used to train a classifier, and the ability of the classifier to predict a particular stimulus attribute is then tested. This approach was adopted in the study described in chapter 3. Third, functional and effective connectivity studies can indicate how different regions interact, and can be interpreted in conjunction with structural MRI evidence of anatomical connections. For example, Morris et al. (Morris, Friston, Buchel, Frith, Young, Calder, Dolan 1998) found increased connectivity between the amygdala and the right fusiform gyrus during the processing of fearful compared to happy faces, suggesting that the amygdala modulates the fusiform response to fearful stimuli.

I now turn to how the studies presented in this thesis contribute to our understanding of the specific roles of the various brain areas involved in emotion recognition.
In the study described in chapter 3, I used multivariate analysis techniques to investigate whether observed facial emotions elicit distinct representations in the amygdala, and in the FFA. I was not able to find evidence for a representation of emotional identity in the amygdala. This could be interpreted as consistent with hypotheses that the amygdala acts as a general-purpose salience detector, but does not rule out the possibility that this region contains a representation of emotions that was not detected in this study. Similarly, the lack of evidence from this study of such a representation in the FFA does not mean that it is necessarily absent here, and thus does not rule out a role of the FFA in processing the emotional attributes of a face.

In contrast, the second imaging study described in this thesis allows more concrete conclusions to be drawn about the processing of emotion in the brain. First, in comparing BOLD responses during an emotion recognition task with those during a control task, I found a main effect of task in the IFG pars orbitalis and pars triangularis, for all three types of stimulus: faces, voices and abstract animations. This finding adds weight to the idea that regions within the IFG are involved in the top-down aspects of emotion recognition, and that this occurs irrespective of the cues to emotion that are available. Ways in which this putative top-down role of the IFG could be confirmed are described in the subsequent section of this discussion. Second, I found that regions activated by emotional compared to neutral stimuli depended on the modality in which these stimuli were presented, suggesting that the process of emotion recognition begins early on, during the initial sensory processing of such stimuli. Third, the activation of the STS by emotional stimuli in this study supports the evidence from earlier studies that this region plays a role in emotion recognition. One possible role for this region might be in holding a representation of the various sensory cues that might be associated with a particular emotion, across several modalities, and this will be discussed further later on in this chapter.

8.2.2 Social interaction and emotion recognition

The findings of the final two studies in this thesis touch on the impact of social interaction deficits on emotion recognition ability. I first investigated emotion recognition from abstract animations and facial expressions in adults with autism and matched controls. I found a deficit in the recognition of sadness from social movement cues and facial expressions, in the autism participant group. I hypothesised that this might have arisen due to diminished social interest early in development. I then investigated the possible impact on facial emotion recognition of diminished gaze fixation, using a posed smile detection task. I found that the adults with autism were impaired on this task, and looked less often at the eyes of the faces, and concluded that a lack of interest in the eye region, or the face in general, might have led to an absence of the expertise necessary to complete this task.

In the explanation for both of these findings, I have hypothesised that the common cause might be a lack of social interest over a prolonged period of time, similar to that

posited by 'motivational/affective' accounts of face processing abnormalities in autism (Dawson et al., 2005). A lack of social motivation, i.e. reduced interest in other people in general, could lead to impaired sadness recognition as the sadness of another individual has no immediate implications for one's own welfare. Thus, an individual with no inherent social curiosity would not gain expertise in identifying sadness. In the case of the identification of posed smiles, which relies on using information from the eye region, a lack of experience in looking at the eye region, which would normally be acquired during the extensive eye-contact that accompanies everyday social interaction, would lead over time to an inability to perform this task, due to a lack of expertise in interpreting cues from the eyes.

Both of these explanations highlight the importance of experience with particular stimuli over the course of development, rather than innate neurobiological factors alone. This idea needs further investigation, as it was not formally tested in these studies, and is only one possible explanation of the results from these two studies. If it is the case that experience is an important factor in the development of these emotion recognition skills, an interesting question would be when this experience needs to occur – whether it needs to be during childhood, or whether compensatory training later in life can reduce such impairments.

It is plausible that a person's emotion recognition ability could in turn influence his or her social interaction skills. In chapters 6 and 7 I have discussed the social difficulties which might arise if a person with autism were impaired in the emotion recognition skills under investigation. In both of these studies I found that performance on these tasks correlated with social interaction ability, suggesting that this might indeed be the case.

It seems, therefore, that there is a complex interplay between social interaction and emotion recognition skills. Social interaction and social curiosity ensure that a person is exposed to the cues indicative of a person's emotional state, and gains experience in interpreting these cues. These emotion recognition skills then improve a person's social interaction ability. This makes it difficult to interpret the findings from the correlational analyses conducted in chapters 6 and 7. If a person with autism is poor at emotion recognition, is this contributing to their social interaction difficulties, or is

it a lack of social experience that causes both the difficulties in social interaction and the emotion recognition deficit?

8.2.3 The neural basis of emotion recognition deficits

I will now attempt to relate these ideas to our current understanding of the brain basis of emotion recognition by considering, firstly, a possible neurobiological account for the emotion recognition deficits observed in these studies and, secondly, how exposure to and expertise with social stimuli might influence the processing of emotion in the brain.

The sadness recognition deficit in autism described in chapter 6 was manifest for both facial expressions and movement patterns. In neurobiological terms, the most parsimonious explanation for this deficit is an abnormality in a single neural substrate or pathway. However, it is uncertain at what level this abnormality might arise – it might be with the representations of these cues themselves, with pathways which are necessary for the development of these representations, or with mechanisms involved in the recovery of information from the representations.

A deficit that is specific to the recognition of a single emotion, such as sadness, would be easier to explain if representations of individual emotions were held separately in different brain regions. However, as discussed in the introduction, evidence for neural substrates specific to the recognition of a particular emotion is limited to disgust and, to a lesser extent, fear. An alternative possibility is that perceptual cues associated with the various emotions we can recognise in others might in fact be represented in a common brain region.

Where might such a representation be sited within the brain? In chapter 3 I considered both the amygdala and the FFA as candidate regions for a representation of facial emotions. However, an alternative candidate region might be the superior temporal sulcus (STS). As discussed in the introduction and in chapter 5, the STS is activated by emotional stimuli. The STS is also sensitive to stimuli in many modalities, and thus could conceivably hold representations of the various possible perceptual cues that could indicate a particular emotion.

With a representation such as this, how might an emotion-specific deficit arise? One possibility is that, in autism, the representations for cues to a particular emotion never fully develop. It is plausible that these representations develop in an experience-dependent manner, which relies on the direction of attention towards the appropriate stimuli.

A deficit in the recognition of sadness, as described in chapter 6, could be explained by a lack of attention to people displaying sadness, and thus a failure to build representations within the STS of the cues associated with this emotion. Likewise, an inability to distinguish posed from genuine smiles, as described in chapter 7, could be explained in terms of reduced exposure to the eyes of others, and thus a poorer representation in the STS of the ways in which the appearance of the eyes varies according to the emotional state of their owner.

If reduced social interest was indeed the reason for the emotion recognition difficulties reported in this thesis, the core neurobiological deficit would lie not in the region where these representations are held, but rather in the neural system which is responsible for directing attention towards the stimuli in question. This suggests the possible involvement of another brain region - the amygdala.

In the introduction to this thesis I discussed the idea that the amygdala's role might be to 'flag up' stimuli which deserve attention, or further processing. Facial expressions of fear are one example of this type of stimulus, but in normal individuals the amygdala is also activated by sad stimuli, as detailed in chapter 6. These are not signals of threat, but nevertheless appear to be flagged up as significant. It is possible that the amygdala could enhance the processing of such stimuli directly – the amygdala does have strong functional connections with the STS. There is evidence that the amygdala enhances cortical processing in other brain areas, namely the FFA. In normal subjects, the FFA response to a face is modulated by its emotional expression – responding more strongly to fearful, rather than neutral faces. In subjects with lesions to the amygdala, this does not occur (Vuilleumier et al., 2004). However, the effect of the amygdala on representations within the STS could also be an indirect one. If the amygdala flags the sadness of another individual as significant, this could

cause a person to pay more attention to this individual, and therefore indirectly gain exposure to cues of sadness.

An impairment in this system could thus arise either through an abnormality in the amygdala itself, or through abnormal amygdala-cortical connectivity, meaning that the amygdala responds to sad stimuli but can not influence other brain regions such as the STS. As addressed in the introduction to this thesis, there is evidence that both of these are features of the neurobiology of autism. The amygdalae show evidence of enlargement in autism, at least in younger individuals (Stanfield et al., 2007), and a recent study has shown that in autism the amygdala shows reduced functional connectivity with adjacent cortex during the processing of facial expressions (Welchew et al., 2005).

It is possible that a similar abnormality might underlie the failure to develop a representation of visual cues from the eye region. There is some evidence that the amygdala might indeed flag up eyes as stimuli worthy of further attention. As described in the introduction to this thesis, lesions to the amygdala lead to a failure to look at the eyes when performing face-based tasks (Adolphs et al., 2005). There is evidence that the amygdala response to eyes is abnormal in individuals with autism, although the correlational nature of the data available on this subject makes it difficult to infer a causative relationship. As described in the introduction to this thesis, individuals with autism who have a higher level of activity in the amygdala spend longer looking at the eyes of faces (Dalton et al., 2005). This could indicate that the amygdala is driving this looking behaviour. However, Dalton et al. instead conclude that the amygdala activation is a consequence of eye fixation, rather than a cause, and propose that the amygdala is hyper-reactive to eyes in autism, leading individuals with autism to find eyes aversive and actively avoid contact. This sense of aversion is congruent with the descriptions of some experimental participants (personal observation). This is not congruent with the idea that the amygdala fails to flag eyes as significant, but is another mechanism by which amygdala dysfunction could lead to a failure to look at the eyes. Novel experimental or analytical techniques may be necessary in order to uncover the direction of causation behind eye contact and amygdala activity.

Finally, it is worth considering the wider implications of the idea that exposure to social stimuli is critical in the development of the brain mechanisms necessary for aspects of social cognition, such as emotion recognition. One interesting question is whether interventions later in life have the potential to influence the 'wiring' of the brain, and improve social cognitive skills. If so, this would have implications for the education of children, and perhaps even adults, with autism, as it would mean that the adverse effects of a lack of social exposure could to some degree be reversed, even if the core neurobiological differences underlying this disorder could not be. This is an area in which more research is needed, and the results from existing neuroimaging studies are not promising at present. As mentioned in the introduction to this thesis, a study investigating whether training on a facial emotion recognition task would enhance the fusiform response to faces in individuals with autism found no increase in fusiform activity (Bolte et al., 2006). However, it should be noted that participants did improve in their ability to perform the task itself. This itself is of significance, as although the question of whether normal FFA response patterns can be elicited is interesting from a neurobiological perspective, in terms of implications for education it is improvement on behavioural measures that is more important.

8.3 Future directions

As discussed earlier, one goal in emotion recognition research over the coming years will likely be establishing how the brain regions implicated in this process interact with one another to form an emotion recognition network. In terms of functional imaging, this means a shift away from the simple search for regionally specific effects, for which univariate approaches to analysis, such as SPM, are particularly useful.

As the emphasis moves towards identifying specific roles for the regions in this emotion recognition network, decoding-based approaches, which probe the information coded in the activity of a particular brain region, will likely prove useful. This includes the use of multivariate analysis techniques, which investigate the information encoded in the spatial pattern of activity across voxels. This information is not used in conventional univariate analysis, in which the BOLD response at each voxel is considered separately. Increases in the available field strength enable fMRI at

increasingly high resolution, allowing the collection of data from more voxels for a given brain area. However, due to the indirect way in which the BOLD signal indicates brain activity, smaller voxel sizes are only useful up to a certain point. It is therefore likely that techniques other than fMRI will contribute to the study of how precisely the information employed in the process of emotion recognition is represented in the brain.

In addition to clarifying the nature of the representations held within brain regions, another avenue for further investigation is into how these regions interact with one another. Further assessment of the connectivity between brain regions in fMRI studies could prove useful for this purpose. For example, the effect of task found in the IFG in this and other emotion recognition studies suggests a role for this area in the top-down aspects of emotion recognition. Following on from this, it might be profitable to assess the connectivity between this and other brain regions in an fMRI study. The STS has been implicated in emotion recognition in this and other studies. One might predict that connectivity between the IFG and the STS would be greater when a participant is performing an emotion recognition task than during a control task, reflecting top-down influences of the IFG on emotion-processing regions within the STS.

Two of the studies described in this thesis investigated the processing of emotional stimuli in autism. As discussed in the introduction to this thesis, there have been some conflicting findings in this field over the past few decades, and the extent to which individuals with autism are impaired in their recognition of emotion is still a matter of debate. With the current high volume of research into the social cognitive abilities of individuals with autism, this debate is likely to continue. A better understanding of the nature of the social cognitive deficits present in autism will have implications for the education and training of individuals with this disorder. However, it is also likely to lead to advances in the understanding of the core neurobiological deficit of this disorder, which is still unknown. Some years ago the realisation of the importance of the amygdala in social cognition led to the 'amygdala hypothesis of autism', and the idea that dysfunction of this region was key to the development of this disorder (Baron-Cohen et al., 2000). As evident in this thesis, this idea is still very influential in the design and interpretation of studies into social cognitive abilities in autism.

However, another brain area, long known to be important in social cognition, has recently been proposed as key to the development of autism – the STS (Zilbovicius et al., 2006). Given the STS's well-documented role in the perception of socially salient stimuli (Allison et al., 2000), this idea could have implications for theories of how abnormalities in the processing of such stimuli arise during autism. Abnormalities in face processing in autism, for example, have been a subject of much debate, with some disagreement over the relative importance of perceptual/cognitive and motivational/affective factors (Dawson et al., 2005). The idea that the core deficit in autism might be in the STS is still a speculative one, but given the hypothesised perceptual role of this area, in contrast to the amygdala's purported role in the flagging of salient stimuli, this idea might signify a shift towards perceptual/cognitive accounts of face processing deficits in autism, and away from motivational/affective ones. In any case, it is likely to shape future studies into social cognitive abilities, including emotion recognition, in autism.

With regard to future research into social cognition in autism, one issue which needs to be addressed is the large degree of heterogeneity within the autistic population. There is a wide spectrum of ability, both in terms of general intellectual ability, or IQ, and in terms of severity of autistic symptoms. This proved to be a limitation to the studies on autism presented in this thesis, which is addressed in the subsequent section of this discussion. Given this high level of variability, the idea that a single neurobiological deficit might underlie the social cognitive deficits seen in this disorder is probably something of an oversimplification. Research into the genetic basis of autism makes use of the concept of an 'endophenotype' (Gottesman & Gould, 2003) – a genetically determined cognitive trait that is more common in individuals with autism and their relatives than in the general population, and that contributes, along with other such traits, to the emergence of autistic symptoms. Behavioural and neuroimaging research into autism could benefit from the idea that underlies this approach – that multiple genes, affecting a number of different traits, lead to the development of autism in some individuals. Individuals with autism will not share all of these genes, or all of these traits. Therefore, a symptom-based approach in such research might be fruitful, in which individuals are included in the study based on the presence of particular traits or symptoms, rather than simply on the basis of a diagnosis of autism (McCaffery & Deutsch, 2005).

Another approach that may be beneficial in the continuing investigation of social deficits in autism is the development of more naturalistic testing paradigms. Over the past few years it has been recognised that, particularly in high-functioning autism, there can often be a gulf between an individual's social cognitive ability as assessed in formal tests, and his or her competence in everyday social interaction (Klin, Jones, Schultz, Volkmar & Cohen, 2002a). Some high-functioning individuals can score relatively well on formal tests, such as measures of Theory of Mind (Klin, Schultz & Cohen, 2000) but still have difficulties with normal social interaction. There is some evidence that more naturalistic tests of Theory of Mind, which rely more heavily on empathy, are more likely to reveal deficits in individuals with autism (Ponnet, Roeyers, Buysse, de Clercq & van der Heyden, 2004). The tests used in this study required the participant to observe videotapes of real social interactions.

There is thus a need for the development of techniques to tap into, and ideally quantify in some way, the real-life social interaction behaviour and social perceptual ability of individuals with autism. One aspect of this might involve measuring behaviour and responses in real time, rather than 'offline', and in situations where there are multiple demands on attention. A more naturalistic approach has been adopted in a recent study with the amygdala lesion patient SM (Spezio et al, 2007b). Here, the degree of eye contact of SM was investigated during conversations with real people, as a follow-up to findings that she failed to look at the eye-region of photographs (Adolphs et al., 2005). A similar approach might be fruitful in the study of eye-gaze behaviour in with individuals with autism. One might expect differences between gaze behaviour to the eyes of a photograph, which can not 'look back', and to the eyes of a person, who can.

In addition to generating general ideas about the future directions of emotion recognition research, the studies in this thesis have also highlighted more specific avenues for research. The imaging study described in chapter 5 identified brain regions in the posterior temporal and superior parietal cortices that were involved in the processing of emotion as conveyed by abstract animations. Chapter 6 describes the finding of a deficit in the interpretation of these stimuli in individuals with autism. A natural progression from these two studies would be to conduct an fMRI study with adults with autism. One might predict that emotional stimuli would elicit less

activation in these regions in adults with autism compared to controls. Moreover, as the emotion recognition deficit in autism was most pronounced for sad stimuli, it might be for these stimuli that there was a difference in activation level between subjects with autism and controls. This would indicate that a poorer representation of the perceptual cues associated with sadness in these individuals was behind their deficit in sadness recognition.

8.4 Limitations

I will now address some limitations to the methodology of the studies described in this thesis, which have become apparent during or since their completion.

Firstly, in the study described in chapter 3, I was unable to demonstrate evidence of a representation of emotion identity in the brain regions studied. This could indicate that the representation lies elsewhere, but it is equally possible that the result arose due to a lack of power in this study. Studies such as this, in which the BOLD data are used to train a classifier, require a large amount of raw data, as there will be a certain amount of noise present in the data, and any patterns present need to be detectable above this level of noise. This means that multivariate studies typically require a large number of measurements (brain volumes) for each condition. This can be facilitated by looking only at a small region of the brain, so only a small number of 'slices' is needed, reducing the TR – the time needed to collect each volume. However, it still means a large number of trials per participant, and thus a long time in the scanner, often performing a highly repetitive task. With naïve participants such as those used in this study, there is therefore a limit to the amount of data that can be collected. The situation could be improved by using experienced participants who are willing to spend longer in the scanner, and studies of this type are therefore often performed on members of the research team themselves. Another option is to ask a simpler experimental question. In my study the classifier was trained on four different conditions. Limiting the experiment to two conditions would double the amount of data that could be collected for each condition.

The second limitation also concerns the difficulty of collecting sufficient data, and is concerned with the relatively small sample sizes common in studies of adults with

autism, such as those described in chapters 6 and 7 of this thesis. Studies with samples of similar size to those in this thesis are common, due to the manifold difficulties in recruiting a large number of adults with autism. These include the inherent social anxiety which makes many such individuals unwilling to take part in research, or to travel to an unknown place to do so. Another issue is that administration of an instrument such as the ADOS to the sample to confirm diagnosis often identifies individuals as not meeting the cut-off criterion for a diagnosis of autism, despite the fact that these individuals present to the study with a diagnosis of autism which they obtained elsewhere. The prevalence of studies based on small sample sizes is a problem because of the marked heterogeneity within the autistic population, even amongst individuals who fall at the 'high-functioning' end of the autism spectrum. This makes for a large amount of variability within the experimental sample, but also makes it difficult to generalise from the experimental findings to the autistic population as a whole. This is compounded by the problems arising from the fact that many participants in autism research take part in multiple studies, travelling large distances to do so (personal observation), so similar studies conducted by separate research groups are not necessarily independent. One solution to this is a move towards much larger-scale studies. Another is to adopt a symptom-based approach in autism research, in which a sample is selected not on the basis of a diagnosis of autism, but based on the presence or absence of a particular trait. As addressed in the previous part of this discussion, in the search to uncover the neurobiological basis of these traits, and ultimately of autism as a condition, this approach might prove more fruitful.

A further limitation concerns a difficulty specific to behavioural studies of emotion recognition. As discussed elsewhere in this thesis, the seemingly effortles recognition of facial expressions of emotion in others is acquired at an early age, and even in the case of developmental disorders, there is evidence that high-functioning individuals may be unimpaired in the recognition of at least the basic emotions (Baron-Cohen et al., 1997). This leads to a difficulty in designing tasks to avoid ceiling effects, which can obscure differences that might exist between participant groups.

In testing the recognition of facial expression, a forced-choice paradigm in which a person sees a static photograph of a face and has to select one of a set of emotion

labels will typically lead to a ceiling effect among controls. Over the years a number of imaginative techniques have been adopted to avoid such an effect. Asking the subject to rate the intensity of the emotion present in a face, as adopted by Adolphs et al. (1994) in their study of amygdala lesion patient SM, can provide a more sensitive measure. Also, dynamic stimuli can be created which morph from a neutral to an emotional expression (e.g. Frigerio, Burt, Montagne, Murray & Perrett, 2002). These can be used to determine the amount of information that needs to be provided before an individual can recognise a face as displaying a particular emotion. Again, this is a more sensitive method of investigating possible emotion recognition deficits.

In the studies described in this thesis, this issue was addressed by deliberately choosing more challenging or unusual tasks. In the study described in chapter 6, the interpretation of abstract animations was chosen partly because of the novelty of these stimuli. It was hoped that a lack of expertise of the autism or control participant groups with these stimuli would avoid ceiling effects. Likewise, in the study described in chapter 7, the discrimination of genuine from posed smiles was chosen as a more subtle facial processing task than the recognition of basic emotions. However, as highlighted in the discussion of this chapter, it was not possible to avoid ceiling effects in the control task. If more time were available to continue this research, it might be possible to develop a more suitable control task. Digital manipulation of the stimulus photographs could be used to facilitate this. To rule out the possibility that impairment on the posed smile task resulted from a general impairment in fine perceptual discrimination in the autism group, the control task would ideally also involve fine perceptual discrimination. However, due to the fact that this task was being used to test a hypothesis about the effects of attention to the eye region, it would be important that such a control task did not require attention to the eyes. Thus, fine discrimination of eye colour (which could be easily digitally manipulated) would not be a suitable control task. A task which did not rely on any particular facial region might be more appropriate. One possibility is that photographs could be manipulated to alter the level of symmetry in the facial features. The control task would involve discriminating entirely symmetrical from slightly asymmetrical (unmanipulated) photographs, and the subtlety of the manipulation could be tailored to ensure that the task was at an appropriate level of difficulty.

The issue of matching experimental and control tasks for difficulty was also a limitation of the imaging study described in chapter 5. Here, I contrasted brain activity during performance of an emotion recognition task with that during performance of a control task. In both cases, participants had to view or listen to an emotional stimulus, before choosing the correct response from two possible options. In the control task, the two possible options were always the same (male and female for the face or voice stimuli, and top and bottom for the animation stimuli). In the experimental task, however, there were five possible emotions which could appear in the list of two response options. Therefore, during observation of the stimuli the participant had to hold five possibilities in mind, rather than two. This meant that the experimental task might conceivably have been more difficult than the control task. This provides a potential confound in neuroimaging studies, as the areas activated by the main effect of task might be related to task difficulty rather than, in this case, emotion processing per se. In this study, however, behavioural scores for the two tasks were not different, so it did not appear that participants found the experimental task more difficult than the control task.

8.5 Concluding remarks

In the studies described in this thesis I have used a variety of approaches to investigate the neural basis of emotion recognition, but have only been able to address a small number of experimental questions in what is a large and ever-growing field of research. As discussed in this thesis, many issues investigated in these studies remain unresolved, and a subject of ongoing debate. It is likely that novel experimental techniques, included some of those adopted in this thesis, have the potential to answer some of these questions in future.

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